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THE LICHEN WOODLANDS IN LABRADOR AND THEIR IMPORTANCE AS WINTER PASTURES FOR DOMESTICATED REINDEER

BY

ILMARI HUSTICH

HELSINKI—HELSINGFORS 1951

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Introduction.

To the best of the author's knowledge the lichen forests in the Labrador Peninsula have not been studied to any great extent. The lichen forests are very common in the Labrador taiga and forest-tundra. Their principal importance in the future will probably be as winter pasture for domesticated reindeer.

As early as 1907 the famous Labrador doctor, WILLIAM GRENFELL, introduced domesticated reindeer (280 animals) into Newfoundland-Labrador. »In this matter Dr. Grenfell unfortunately was not successful: a systematic plan for the pasturing of the herd was not worked out in advance . . . The people, perhaps taking the deer for caribou, soon exterminated the herd . . . My personal opinion is that Dr. Grenfell's idea was excellent in principle, and I am sure that sooner or later new experiments in this matter must be made and will have practical success» (TANNER 1944, p. 794). Lately also for instance Dr. J. ROUSSEAU has touched upon the same idea: »The George River region can accomodate large reindeer herds sufficient for a large population, provided skilled herds-men are hired to train the local inhabitants» (1948, p. 96).

The author endeavours to show that as far as the winter pasture conditions are concerned reindeer could successfully be introduced into Labrador. However, the introduction of reindeer is also a problem of organisation and psychological approach to the natives, as experiences from Alaska show; compare LANTIS 1950.

For valuable help given and suggestions made in the course of this work the author wish to express his thanks to several colleagues and persons: Mr. A. E. PORSILD, Chief Botanist at the National Museum of Canada, Dr. A. L. WASHBURN, Director of the Arctic Institute of North America, the members of the Canadian-Finnish phytogeographic party to the Hudson Bay East Coast in 1947, Mr. W. K. W. BALDWIN, Mr. J. KUCYNIAK, Dr. E. H. KRANCK and Dr. R. TUOMIKOSKI. I also wish to express my gratitude to The Labrador Mining and Exploration Co. and its General Manager, Mr. W. H. DURRELL, for allowing the author to visit the Knob Lake area in Central Labrador in 1948. My first contact with the Labrador spruce lichen forests was made in 1937 on the Finland-Labrador Expedition thanks to Dr. V.

TANNER and Dr. E. H. KRANCK. In 1946 I visited some of the southernmost lichen forests in northeastern Canada (Oskelaneo). The following scientists have assisted in the determinations of the plant species mentioned in the text: Mr. A. E. PORSILD (critical phanerogams), Dr. H. BUCH and R. TUOMIKOSKI (mosses), Dr. S. AHLNER and Dr. V. RÄSÄNEN (lichens). I also wish to thank Miss LAINA RÄSÄNEN for allowing me to use her valuable manuscript on the chemistry of Cladina alpestris; her paper was made under the guidance of Dr. S. SIINTOLA of the Institute of Pharmacology at the University of Helsingfors.

Helsingfors, January 1951.

Ilmari Hustich.

I. The Labrador Forests.

The climatic conditions in the Labrador Peninsula have recently been discussed by TANNER 1944, VILLENEUVE 1948 and HARE 1950. In this connection it should be pointed out that the polar tree-line in Labrador — compared with other parts of the circumpolar coniferous belt — is very southernly situated. The forest belts are unusually compressed; the lichen woodlands of the taiga region are encountered at a comparatively short distance north of the luxuriant Great Lakes forests.

Map 1a (after H 1949[1]) shows the main forest regions of the Labrador Peninsula:

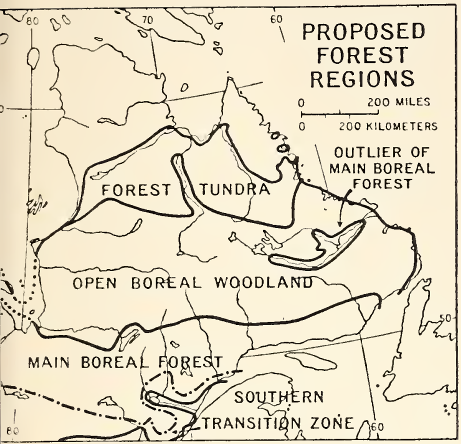
A. *Forest-Tundra,* which extends from the polar tree-line to the approximate northern limit of continuous forests. In this »Forest-Tundra Ecotone» (sensu MARR 1948 and HARE 1950) the tundra occupies a large area and forests occur mainly along the rivers, in sheltered valleys, on southern slopes etc.

B. *Taiga* (Open Boreal Woodland Region sensu HARE, l. c.), the region between the northern limit of continuous forests to the approximate southern limit of the lichen forests.

C. *Southern Spruce Region* (Main Boreal Forest Region sensu HARE, l. c.), the transition region between the taiga and the Great Lakes-St. Lawrence forests.

Recently HARE (l. c.) has suggested a slightly different forest region classification; see Map 1b; compare also HALLIDAY 1937.

[1] The expressions H 1949, H 1948 etc., refer to the author's papers; see p. 46.



Map. 1. The main forest regions of the Labrador Peninsula, according to HARE's (1950), to the left, and the author's opinion (1949).

The *main forest types* (tentative) in the Labrador Peninsula are the following:

Dry forests: 1. conifer lichen forest, 2. conifer dwarf shrub lichen forests and 3. conifer blueberry forests. Jack pine has a fairly restricted distribution in the Labrador taiga, and pine lichen and pine dwarf shrub lichen forests, which are very common in northern Europe and there form the principal winter pasture for reindeer, are, therefore, not common in the Labrador taiga.

Moist forests: 1. conifer feather moss forest (i. e. a forest type where the ground is covered by dominant feather moss species), 2. conifer bunchberry (*Cornus canadensis*) forest, 3. rich conifer forest and 4. mixed groves.

Wet forests: 1. open bog forests (= the northern »forest of sticks», usually tamarack and black spruce), 2. black spruce muskeg and 3. rich swamp forests (white spruce and tamarack in the taiga region, often cedar in the southwestern part of the Peninsula).

For general descriptions of these forest types, compare H 1949. HARE (l. c.) has suggested the following names for these forest type series: dry forest = lichen woodland, moist series = close-forest types and wet series = muskeg types.

*

This paper deals with the conifer lichen and conifer dwarf shrub lichen forest of the Labrador taiga and forest tundra region. As transition types between these

two main forest types are frequent, the collective name lichen woodland is used here for both types. This expression does not include the conifer blueberry forest of the dry forest series as defined above and in H 1949.

II. The Lichen Woodlands in Labrador.

In the lichen woodlands of the taiga and the forest tundra region the following tree species occur: black spruce, *Picea mariana* (Mill.) BSP, white spruce, *Picea glauca* (Moench.) Voss., tamarack, *Larix laricina* (DuRoi) K. Koch, jack pine, *Pinus Banksiana*, Lamb., white birch, *Betula papyrifera*, March. (coll.) and, more rarely, balsam fir, *Abies balsamea* (L.) Mill. and aspen, *Populus tremuloides* Michx. The approximate northern tree-lines of these species appear on maps in H 1949. Map 2 shows the northern tree-line of white and black spruce and the approximate distribution of lichen wood-

Map. 2. The northern tree-line of spruce (white and black spruce). The shaded area gives an approximate idea of the extension of the lichen woodlands in Labrador.

land in Labrador. As mentioned above, the lichen woodlands here include two forest types: the more or less pure conifer lichen forest and the conifer dwarf shrub forest. These types are described in brief below.

Pure lichen forest (Fig. 1) is an important primary forest type in the Labrador taiga and forest-tundra. It covers the elevated deltas, glavifluvial deposits, river-terraces, ridges, plateaus, ancient beaches, old dunes etc. It seems that this type gradually changes into dwarf shrub lichen forest: if the »parklike» lichen woodlands grow denser the light conditions change and the lichen species gradually give way to moss species.

In the Labrador Peninsula there are two common types of lichen forests, the black spruce lichen forest and the white spruce lichen forest; pure jack pine lichen forests and tamarack lichen forest are rare. Mixed spruce ($\pm$ tamarack) lichen or dwarf shrub lichen forests are often seen (Fig. 2). Black spruce is the commonest dominant tree species in the lichen forests. Where the glacial till is of less acid origin and the sand clayey, white spruce dominates.

The trees are low, rarely more than 10 meters high. Where the lichen forest is dominated by black spruce a peculiar tree-form often develops, the

Fig. 1. White spruce lichen forest. Great Whale River. Photo W. K. W. BALDWIN 1947.

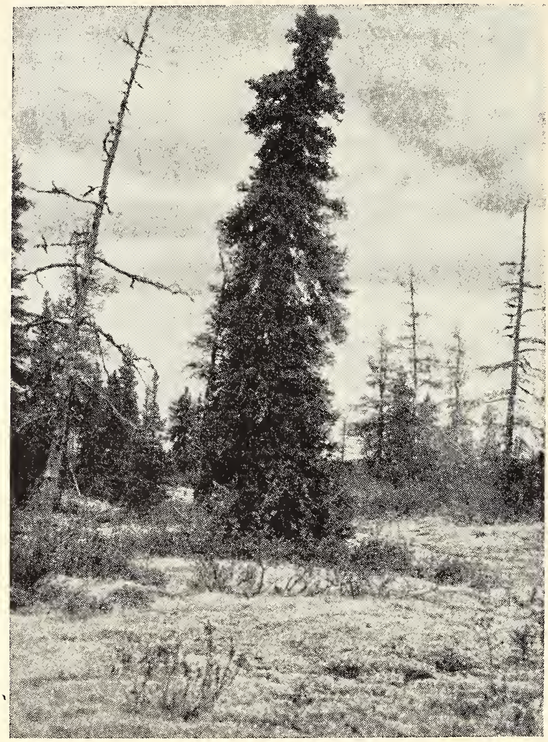


Fig. 2. White spruce (tamarack) dwarf shrub lichen forest in the interior of the Labrador Peninsula, from the upper part of the (Ungava) George River valley, about 55° 26′ north. Lat. Photo J. ROUSSEAU 1947.

candelabrum spruce, described in H 1949 and H 1950; see Figs. 3—4. This tree-form occurs, as it seems, all over the taiga; it deserves a closer taxonomical and ecological investigation.

The trees stand some meters, or up to 10—15 meters apart (Fig. 18). The ground is covered with almost pure lichen, usually of the most important caribou lichen species, i. e. *Cladina alpestris;* for details, see below p. 27. In the tracts (see Fig. 7) between the »facets» or »polygons» formed by the lichen cover in the open spaces between the scattered trees, crowberry (*Empetrum hermaphroditum*) and mountain cranberry (*Vaccinium Vitis-Idaea* var. *minus*) occur, as do also some depressed seedlings of the dominant tree species. Under the trees, i. e. in the shade of the trees, feather mosses (*Hylocomium splendens* and *Pleurozium Schreberi*) grow together with scattered tufts of the above-mentioned dwarf shrub species.

The author has not seen pure *pine* lichen forests (see Fig. 8 in H 1950) in Labrador, but it is very probable that some patches of this type are to be found in SW Labrador. Tamarack lichen forests occur in small patches only; tamarack, however, is often seen mixed in the spruce lichen forests. In some places white birch grows together with the spruce; compare Fig. 17.

The dwarf shrub lichen forests have probably for the most part developed from pure lichen forests. The occasional individuals of dwarf shrub species in the lichen forests have grown larger, the seedlings have — extremely slowly — developed into young trees and thus increased the shadow in the open forest. Very often dwarf birch (*Betula glandulosa*) occur in such forests, as does Labrador Tea (*Ledum groenlandicum*) also. In the shade of the canopy the same ground vegetation appears as described above. However, the dominant species in the ground cover in open places also in this type of forest is the caribou (reindeer) lichen species *Cladina alpestris*. The bilberry species are numerous in this type of forest: dwarf bilberry (*Vaccinium cespitosum*), sweet bilberry (*V. angustifolium*) and alpine bilberry(*V. uliginosum* var. *alpinum*), which in the North is a fairly »xerophilous» plant. Occasionally velvet-leaf bilberry (*V. myrtilloides*) forms small tufts in the lichen cover. In the southern part of Labrador the lambkill (*Kalmia angustifolia*) is common in the dwarf shrub lichen forests, where jack pine is often the dominant tree species.

The lichen forests are usually dominated over large areas by one tree species only, but the dwarf shrub lichen forests seem to be more mixed (Fig. 2). Balsam fir and aspen are rarely encountered in dwarf shrub lichen forests.

The lichen woodlands cover large areas in the Labrador taiga and in the forest tundra. They also penetrate into the southern boreal region; the author has seen fairly pure lichen woodlands as far south as near Oskelaneo Lake. The large areas covered by glacial deposits in the interior of the Peninsula are mostly covered with this lichen woodland. (These forests are easy to distinguish from the air (Fig. 18), and sometimes it is as easy to see which tree species is the dominant: black spruce in such localities, as already mentioned, is often of candelabrum-form and this large tree-form can be fairly clearly observed from the air.)

The southern limit of the lichen woodlands in Labrador probably coincides well with the main tree-line, described in H 1949. This main tree-line could be called a »*limes labradoricus*» in accordance with recent Swedish investigations of the wellknown limes norrlandicus (Fries 1949). Several important tree species have their northern outposts in a transition zone where the taiga lichen woodlands seem commonly to change into a *Kalmia-Vaccinium-Cladonia* forest (sensu Bellefeuille 1935) with black spruce or *Kalmia-Cladonia*

Fig. 3. Burned spruce dwarf shrub lichen forest in the Knob Lake area in the Central Labrador. Note the typical candelabrum black spruce in the foreground. Photo I. H. 1948.

forest (KUJALA 1944, HEIMBURGER 1946) with jack pine. The relations between the main tree-line or limes labradoricus, the climate, the water-divide and the highest marine limit in southwestern Labrador need, however, more investigation.

In Table I the vegetation of 16 sample plots from two different districts from the east coast of James Bay and Hudson Bay (H 1950) and from the Knob Lake area in Central Labrador is listed, see Map 3. The sample plots are described below in some detail as to their tree stand and their reproduction. There is, as shown by Table I, no sharp distinction between the two main forest types of the lichen woodlands: spruce lichen forests and spruce dwarf shrub lichen forests.

The sample plots are, unless otherwise stated, about 1/40 acre, i. e. 100 sq. meters. The ground vegetation analysis, an ocular estimation only, was made on a typical part of the sample plot, about 6 feet$\times$6 feet. The frequency scale: 3 = dominant, 2 = common, 1 = scattered, $\times$ = occasional individuals of a species.

Abbreviations: wspr = white spruce, *bspr* = black spruce. The expression »*30$\times$6, age 90*» means a tree 30 feet high, 6 inches in diameter 4 feet above the ground, 90 years old at the ground, according to increment borings; »*age 90* (*DBH*)» means the age at about 4 feet above the ground. The expression »*12$\times$16y*» means a seedling, 12 inches high and 16 years old. The age was microscopically determined. The annual rings of the increment cores were counted by Mr. Fritz Bergman using a special microscope constructed by the Swedish expert Dr. Bo Eklund. Owing to the depressed growth of the seedlings on exposed localities, the age determinations are approximate only.

1. *East Coast of Hudson Bay, Sucker Creek.* Rolling terrain of dunes, partly old, partly new, near the mouth of Sucker Creek, about ½ mile from the sea shore. On the sample plot the wspr are partly of »candelabrum» habitus. Rich

Fig. 4. Ground section of a candelabrum black spruce. Note the many centers. Age about 90 years. Great Whale River (H 1950).

production of cones. Trees on the plot: 30 × 6, age 120, 18 × 3, age 45—50 (DBH), 27 × 5, age 90—95 (DBH), 7 × 2, age 55, 6 × 1½, age 45—50.

Reproduction: 4 wspr seedlings, 10 × 36y, 8 × 28y, 4 × 23y and 9 × 18y, of the depressed bushy type of seedlings usually found on lichen heaths in the north.

2. *Hudson Bay, Great Whale River.* N of the river, about 1 mile from the mouth, on the upper terrace, about 300 feet above sea level (?) near the granite hill. The wspr trees are mostly arranged in groups. Snow cover 1—3 feet deep. Samples of the wspr trees: 30 × 6½, age 75 (DBH), 24 × 3½, age 70, 23 × 3½, age 72, 21 × 3, age 75. The crowns of the trees are narrow.

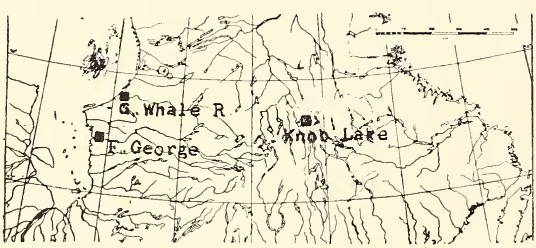
Reproduction: 2 wspr seedlings.

3. *Hudson Bay, Great Whale River.* Sample plot, about 42 × 75 feet, on the elevated delta S of the HBC post. Dominant wspr, appearing partly as candelabrum trees. The surface is slightly rolling, with low depressions, 2—3 feet only, where trees and seedlings occur. On the sample plot a large group (partly a candelabrum tree) with 20 stems with several hundreds of well developed new cones in 1947. The biggest stems: 24 × 5, age 34, 23 × 4, age 28, 21 × 6, age 54 and 21 × 4, age 31, thus fairly fast growing trunks, considering the extreme conditions. On the sample plot there are 4 minor solitary trees: 23 × 8, age 53 with about 1,000 cones, 15 × 5, with about 1,000 cones, 12 × 2½, age 27, with 15 cones, 15 × 5, no cones.

(On the elevated delta wspr seem to penetrate into new territory. No old stumps could, for instance, be seen near the shore. The trees look luxuriant and show a remarkably fast growth after they have passed the »depressed stage», compare the age of the seedlings mentioned below. Many trees in this area have double stems.)

Reproduction: On the 20 wspr seedlings 11 were slightly damaged by frost and partly deformed. For further details; see H 1950, p. 46—47.

4. *Hudson Bay, Great Whale River.* A sandy plain between two low hills about 15 miles inland from the HBC post, about 300 feet above the river. Dominant bspr which here reaches on the average 21 × 4. Several old trees and stumps were seen as were also scattered low bspr bushes. The trees look old, though the increment borer proved that these trees were unexpectedly young; some samples: 24 × 6, age 30 (DBH), 21 × 4, age 43, 18 × 3½, age 23 (DBH).



Map. 3. The geographical situation of the three main localities for the sample plots 1—16.

Reproduction: No seedlings on the sample plot itself, nearby a bspr seedling 7×21y.

5. *James Bay, George Island* (*Fort George*), S-side, bspr dwarf shrub lichen forest. The humus layer under the lichen cover about 1 inch thick. The bspr about 25×5 in average. Nearby wspr and tamaracks on lichen heath. Some bspr trees: 24×5, age 65 (DBH), 27×6, (rich male flowering) age 100 (DBH), 18×4, age 56 (DBH), 8×2, age 70.

Reproduction: Generally good cone production. No bspr seedlings on the sample plot. Nearby two wspr seedlings of the bushy type: 5×12—13y and 3×15y.

6. *Hudson Bay, Great Whale River.* Near the sandy plain S of the First Falls, about 8 miles inland from the HBC post. Scattered tamaracks grow among the dominant bspr. Samples of trees: bspr 27×5, age 80 (DBH), 24×5, age 71 (DBH), tamarack 27×6, age about 77 (DBH), tamarack 27×5, age about 67 (DBH).

Reproduction: not noted.

Fig. 5. Reindeer (caribou) lichen forming tufts or »pancakes» with large tracts; compare Fig. 10. A typical picture of an exposed part of lichen woodland. Great Whale River; sample plot 8. Photo I. H. 1947.

Table I. Vegetation cover on sample plots from lichen woodlands.

Sample plot No.	Hudson Bay Coast								Central Labrado[r]					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Vascular plants:[1]														
Empetrum hermaphroditum ..	(×)	(1)[2]	(×)	—	×	1	—	×	—	1	×	2	2	1
Vaccinium Vitis-Idaea var. minus	(×)	(1)	(1)	—	×	—	×	×	—	×	—	×	×	×
Betula glandulosa	—	—	—	1	2	—	3	2	1	1	1	1	—	2
Ledum groenlandicum	—	—	—	×	×	1	—	1	×	1	×	×	1	1
Vaccinium uliginosum	—	—	—	—	1	1	—	×	—	1	1	1	×	1
V. angustifolium	—	—	—	1	—	—	—	—	—	—	1	—	1	1
V. myrtilloides	—	—	—	—	—	1	—	—	—	—	—	—	—	—
V. cespitosum	—	—	—	—	—	—	—	—	1	1	—	—	—	—
Lycopodium sabinaefolium[3]....	—	—	—	—	×	—	—	—	—	—	—	—	×	—
L. complanatum	—	—	—	—	×	—	—	—	—	—	—	—	—	×
L. annotinum[4]	—	—	—	—	—	—	—	1	×	×	—	×	—	×
Deschampsia flexuosa	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Hierochloe alpina	—	×	×	—	—	—	—	—	—	—	—	—	—	—
Carex Bigelowii	—	—	×	—	—	—	—	×	—	—	—	—	—	—
Epilobium angustifolium	—	—	×	—	—	—	—	—	—	—	—	—	—	—
Potentilla tridentata	—	×	×	—	—	—	—	×	—	—	—	—	—	—
Geocaulon lividum	—	—	—	—	×	—	×	—	—	—	—	—	1	—
Solidago multiradiata	—	—	×	—	—	—	×	—	×	—	—	—	—	×
Cornus canadensis	—	—	—	1	×	×	—	×	—	—	—	—	—	—
Linnaea borealis[5]	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Juniperus communis[6]	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Salix Bebbiana	—	—	—	—	—	—	—	—	—	—	—	—	—	×
Ribes glandulosum	—	—	(×)	—	—	—	—	—	—	—	—	—	—	—
Trisetum spicatum	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Trientalis borealis	—	—	—	—	—	—	—	×	—	—	—	—	—	—
Pedicularis labradorica	—	—	—	—	—	—	—	×	—	—	—	—	—	—
Cryptogam cover:														
Max. depth of lichen cover (cm) .	12.5	—	9	—	10	—	10	13	—	15	15	15	—	13
Cladina alpestris	3	3	2	3	3	3	3	3	3	3	3	3	3	3
C. mitis	1	2	1	1	×	1	—	1	—	×	—	×	×	1
C. rangiferina	1	×	2	—	×	1	×	1	—	×	×	×	×	×
Stereocaulon spp.	×	×	1	1	×	—	—	×	—	×	×	—	—	×
Cetraria nivalis	1	—	1	—	—	—	—	×	—	—	—	—	—	—

[1] Names according to FERNALD 1950 (exception: *Empetrum hermaphroditum* (Lge) Hagerup; the crowberry in the Labrador taiga region seems to be identical with the Scandinavian species). [2] Brackets indicate plants which grow under the trees only. [3] Var. *sitchense*. [4] Including var. *pungens*. [5] Var. *americana*. [6] Var. *depressa*.

Table I (cont.)

Sample plot No.	Hudson Bay Coast								Central Labrador							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
islandica	—	—	—	—	—	—	—	—	—	—	—	×	×	—	×	—
donia gracilis	×	—	—	—	—	—	—	—	—	—	—	—	×	×	×	—
coccifera	×	×	—	—	—	—	—	×	—	—	—	—	—	×	×	—
isteria arctica	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	×
locomium splendens	(×)	—	—	—	—	—	—	1	—	—	—	—	—	×	×	—
urozium Schreberi	—	—	(×)	—	—	—	—	×	—	—	×	—	×	—	×	2
ranum fuscescens	×	—	—	—	—	—	—	—	—	×	×	×	×	×	×	×
ytrichum spp.	×	—	—	—	—	—	—	×	—	—	×	×	—	—	×	×
rd lichens:																
ctoria jubata	—	—	—	×	×	—	×	×	—	×	—	×	×	—	×	×
ernia mesomorpha	×	—	×	—	×	—	×	×	—	—	—	—	—	—	—	—

7. *James Bay, George Island,* the inner part of the Sside. Spruce (mostly wspr) lichen forest with scattered bspr (also as »candelabrum» trees) and tamaracks. Snow cover here about 2½ feet deep. The area has been slightly cut. Bush layer of juniper and dwarf birch. The trees: 36 × 8, rich cone production, age about 70 (DBH), bspr 30 × 8½, age 55 (DBH), wspr 27 × 5, age 55—60 (DBH). The bspr trees here have low ground branches, the wspr not.

Reproduction: two 2-year old wspr seedlings, in the neighbourhood some tamarack seedlings, 2—3 feet high.

8. *Hudson Bay, Great Whale River.* On a terrace about 150 feet above the river, about 2½ mile inland from the HBC post. Snow cover about 2—5 feet above the ground; the branchless parts of the stems are developed on the windy NW side. The trees show rich cone production. The trees on the sample plot: 33 × 8, age 103—105 (DBH), 27 × 5, age 83 (DBH), 26 × 4, age 105 (DBH), 30 × 8, age about 100 (DBH), 24 × 4, age 72 (DBH), 23 × 4½, age 65 (DBH).

Reproduction: Of the 48 wspr seedlings, 13 had double stems or otherwise showed indications of a »candelabrum tree» form in an early stage. 16 seedlings were more or less deformed. See Figs. 5—8.

9. *Central Labrador, Knob Lake area, 1 mile N of Burnt Creek,* fairly pure at least 100 years old tamarack lichen forest on the flat bottom of a mountain valley, on iron formation. Scattered wspr (bspr candelabrum trees in the neighbourhood). Trees on about 1/40 acre: tamaracks 27 × 6, 24 × 4, age 89 (DBH) 24 × 4, age 107, 24 × 4, age 106, 18 × 4, white spruce bushes 6 × 3, age 82, 3 × 2, 3 × 1. The tamaracks show rich cone production, some with strong heart rot.

Reproduction: 3 older tamarack seedlings, (12—35 years) and 4 younger tamarack seedlings (about 4 years), 1 wspr seedling (about 48 years, 1 feet high).

10. *Central Labrador, Knob Lake area, Lake Gillard,* on a small point stretching into the lake, about 30 feet above the lake level; the bedrock is iron formation. Bspr and wspr.

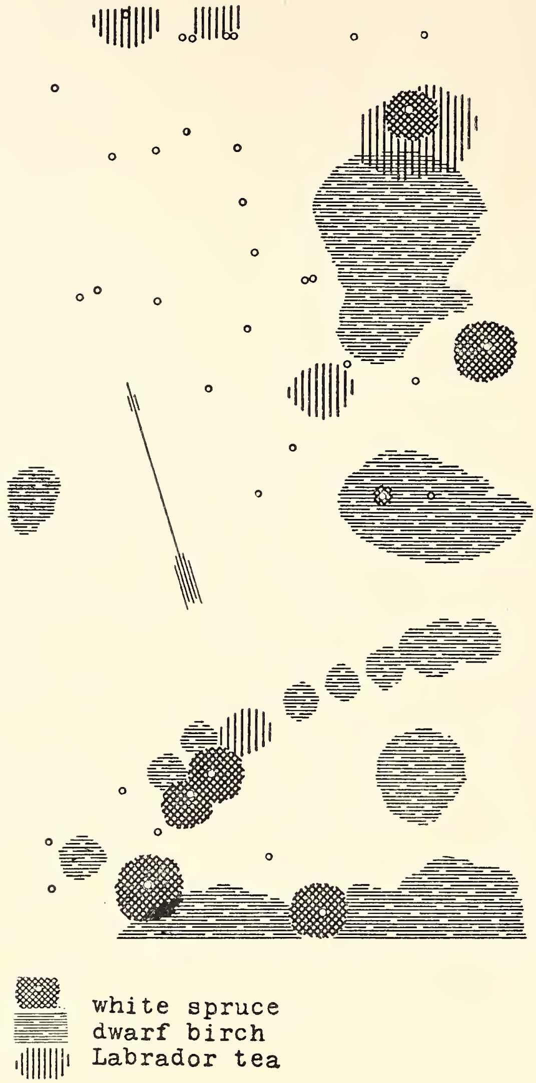


Fig. 6. Lichen-dominated sample plot (8, Great Whale River). The open dots are white spruce seedlings. Scale about 1:200.

On 1/20 acre: wspr 24 × 7, age 85, 24 × 6, age 75, 39 × 14, age 103, 18 × 5, age 63, 15 × 4, age 91, bspr 15 × 3, age 33, 12 × 2, age 60, 3 × 1, age 62, one dead tamarack, 12 × 4. On the sample plot no reproduction because of no openings in the thick lichen cover. Humus layer about 1 inch.

11. *Central Labrador, Knob Lake area, 2 miles N of Burnt Creek,* in the upper part of a S-exposed mountain slope with dominating wspr on stony iron formation,. Near the sample plot a typical 11-armed candelabrum bspr.

Trees on about 1/40 acre: wspr 30 × 10, age 146 (DBH), 33 × 9, age 145 (DBH), 24 × 6, age 148 (DBH), 15 × 3, age 163, 24 × 4, 6 × 2, 24 × 5, 15 × 5, 18 × 5, bspr 24 × 6, 12 × 2, 12 × 2 and 6 × 1. On the bspr few cones, on the wspr no cones.

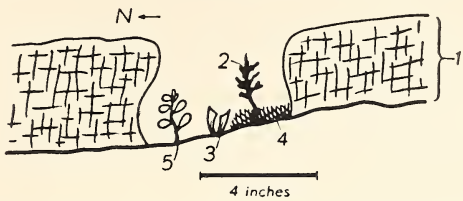


Fig. 7. A 7—9 years old white spruce seedling (2) in a tract between *Cladina alpestris* tufts (1). 3 = *Cladonia* cfr *coccifera*, 4 = *Pleurozium Schreberi*, 5 = *Vaccinium Vitis-Idaea* var. *minus*. Sample plot 8, Great Whale River.

Reproduction: only one (wspr) seedling (about 55 years old, about 1 ½ feet high).

12. *Central Labrador, Knob Lake area, W of Lake Wishart,* SW from the base camp at Burnt Creek, about 300 feet above the lake, on iron formation. Snowdamaged and stunted, very old (up to at least 260 years) white spruces, covered with thick black (*Alectoria jubata*) beard lichens.

On about 1/40 acre the following wspr: 30 × 8, age 247 (DBH), 27 × 11, age 211 (DBH), 24 × 8, age 133 (DBH), 15 × 5, age 155, 12 × 4, 15 × 4, 7 × 4, 6 × 4, 6 × 3, 6 × 3, 6 × 3.

Reproduction: poor, because of the thick lichen cover, 4 wspr seedlings (age 22—40 years, height 5—7) only.

13. *Central Labrador, SW of Knob Lake,* poor bspr lichen forest (on »iron formation») about 100 feet above the lake level; the sample plot is typical for a larger area in the surroundings.

On 1/40 acre about 30 small black spruce trees reaching on average 15 × 2—3, the largest 24 × 5. The trees are about 150—200 years old (samples 15 × 3, age 138, 21 × 4, age 185, 24 × 4, age 182, 23 × 5, age 164 (DBH), 15 × 3, age 172), usually with rot and thick beard lichen cover on the very short branched tree crowns.

Reproduction: only 2 bspr seedlings (both about 55 years old and 1 ½ feet high). No vegetative propagation. The forest looks dead.

14. *Central Labrador, Knob Lake area, Lake Gillard;* on the same point stretching into the lake as mentioned above; the bedrock is iron formation. The sample plot in an area with dominating bspr of usual candelabrum habitus, on a nearly flat rocky plain partly covered with gravel. Trees (usually with heart rot) on about 1/20 acre: 1 candelabrum black spruce with stems 27, 21, 15, 12, 7, 4 and 3 feet high respectively; 7 bspr about 9—21 × 3—6; wspr 3 × 1. Age (DBH) of 3 bspr trees: 9 × 21, age 91, 7 × 16, age 82, 3 × 8, age 54.

Reproduction: 12 seedlings on 1/20 acre, 10 bspr (8—20 years old), 2 wspr (12—21 years).

15. *Central Labrador, Knob Lake area, Lake Gillard,* a stony flat area, iron formation, near sample plot No. 14. Fairly young spruce lichen forest. Trees on about 1/20 acre: 1 candelabrum black spruce with stems 36 (age 143 DBH), 18, 15, 12, 9 and 8 feet high respectively, the main trunk 8.5 inches in diameter; 3 wspr trees 27×5, age 59 (DBH), 18×4, age 52, and 15×4, age 37; 5 wspr trees 27×7, age 70 (DBH), 15×4, age 132, 15×5, age 82, 7×2, age 45, 5×2, age 74, 1 tamarack 13×2, age 47.

Reproduction good because of many barren patches in the lichen cover: 25 wspr seedlings (3—40 years), 19 bspr seedlings (8—37 years) and 1 tamarack seedling (12 years). The distribution of the seedlings on the sample plot, here 1/20 acre, is as usual uneven, on a barren patch in the lichen cover (about 4 sq. m.) 30 seedlings were collected.

16. *Central Labrador, Knob Lakearea, 1 mile NW of Burnt Creek.* Scattered stunted wspr. Snow cover approximately 6 feet. No cones 1948, fairly much 1947 (i. e. cones of flowering year 1946).

On 1/40 acre the following wspr trees: 27×10, age 144 (DBH), 33×9,age 158 (DBH), 30×9, 36×9, age 145 (DBH), 36×11, age 160 (DBH), 27×7, age 137, 27×9 and one nearly dead tree 27×8.

No reproduction; the vegetation on the sample plot is too dense, incl. thick dwarf birch bush.

*

Fig. 8. Detail of sample plot 8, Great Whale River. A probably 15 years old white spruce seedling in *Cladina alpestris* cover, sheltered by Labrador tea stems. Photo I. H. 1947.

For the botanically interested reader it should be mentioned that the following cryptogam species were also collected on sample plots 1—16: Lichens on the ground: *Cladonia amaurocraea*, incl. f. *cetrarioides* (on sample plot No. 1), *C. gracilis* var. *chordalis* (13), *C. pleurota* (14), *Stereocaulon alpinum* (1), *Alectoria ochroleuca* (1, 2, 3, 8), *A. nigricans* (2), *Toninia cumulata* (14)[1]. Lichens on twigs

Table II. The tree stand on sample plots 1—16.

(ws = white spruce, bs = black spruce, t = tamarack).

Sample plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
tree species ..	ws	ws	ws	bs	bs	bs	ws (bs) (t)	ws	t (ws)	bs ws	ws	ws	bs	bs	ws (bs)	ws
age (DBH) ..	120	59	53	29	72	75	65	88	100	52 82	146	197	168	86	84	149
number of trees microsc. measured	2	4	2	3	3	4	2	6	4	bs 3 ws 4	3	3	5	2	2	5
10-year average growth in thickness (0.01 mm)	25	45	130	125	68	—	65	45	—	—	27	30	—	26	112	34

[1] Det. Dr. G. Degelius.

and bark of stems: *Cetraria ciliaris* (5, 7, 13), *C. caperata* (2, 5, 7), *Alectoria simplicior* (5), *A. implexa* (7), *Parmelia sulcata* (3, 5, 7), *P. physodes* (2, 3, 5, 7, 13), *P. obscurata* (12, 13), *Parmeliopsis aleurites* (7), *P. pallescens* (15), *Ramalina Roesleri* (3, 7), *Lobaria scrobiculata* with *Rinodina turfacea* (7), *Pertusaria multipunctata* (13), *Mycoblastus sanguinarius* (13), *Mycocalicium savonicum* (13). Mosses: *Dicranum rugosum* (2), *D. majus* (14), *Polytrichum piliferum* (15, 16), *P. juniperinum* (1, 8, 15, 16), *Ptilidium ciliare* (12), *Lophozia ventricosa* (9), *Barbilophozia Hatcheri* (14), *Orthocaulis Kunzeanus* (15), *O. attenuatus* (9, 15). It should also be noted that the beard lichen species *Alectoria nidulifera* and *A. sarmentosa* were found on similar localities.

The notes on sample plots 1—16 are partly incomplete; some sample plots have been more closely studied than others. Also, it must be noted that only ocular estimation was used in the vegetation analyses. If, however, all 16 sample plots are taken together they should give a fairly accurate picture of the average ground vegetation on lichen woodlands in the Labrador taiga. I also refer to the somewhat more detailed notes in H 1950, which also include two sample plots from a jack pine dwarf shrub lichen forest. *The main feature which all sample plots have in common is, of course, the dominance of Cladina alpestris.* Of the 26 vascular plants mentioned in Table I some must be considered as temporary intruders only. There are certain minor differences in the ground cover of the sample plots from the Hudson Bay coast and from the Knob Lake area, but the vegetation analyses are too few to allow any generalisations.

Table II illustrates the character of the tree stand on sample plots 1—16.

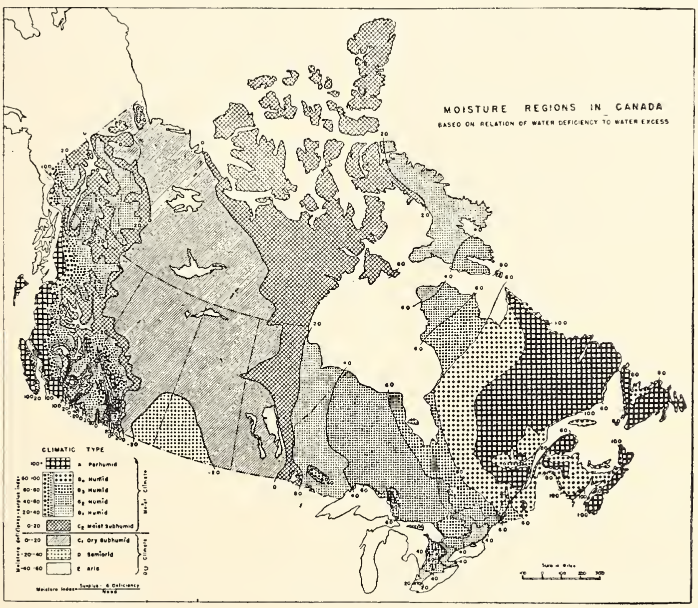
For details regarding growth in thickness, compare H 1950.

It appears from Table II that the age of the tree-stand varies; sometimes the trees are remarkably young, at least as measured at breast height. Generally, however, the trees in the lichen woodlands are old and their radial growth very slow. The white spruce grows on such localities usually as slowly as the black spruce, which is clearly evident from Table II (note the growth in thickness on sample plots 1, 11, 12, 16) as also from Fig. 16.

III. Lichen Woodlands in Other Parts of the World.

Lichen and dwarf shrub lichen forests are circumpolar. They are common in the Canadian taiga belt and they are found in the Eurasian taiga, particularly in the glaciated regions, on glacifluvial terraces and elevated deltas, on ridges and sandy plateaus, on ancient beaches, etc. The lichen

woodlands or »Park-like forests» (sensu RAUP 1946) are particularly characteristic of northeastern Canada, but they are also found in northwestern Canada. From the Great Slave Lake region RAUP gives the following description: »The trees in the park-like forests are widely spaced and branched all way to the ground. There is little or no shrubbery, but the soil is frequently covered with a dense growth of bunch lichens and mat-forming shrubs. The following list is typical of the timber which is common on sand plains: Primary spp.: *Picea glauca, Betula papyrifera* var. *neoalaskana**, *Cladonia rangiferina, Cladonia alpestris, Cetraria islandica.* Secondary spp.: *Juniperus communis* var. *montana, Calamagrostis purpurascens**, *Salix Bebbiana, Betula occidentalis* (= *B. microphylla*), *Pulsatilla ludoviciana**, *Saxifraga tricuspidata, Geocaulon lividum, Empetrum nigrum, Epilobium angustifolium, Arctostaphylos Uva-ursi, Vaccinium uliginosum, Vaccinium Vitis-Idaea* var. *minus, Pedicularis labradorica, Solidago multiradiata*» (RAUP 1946, p. 37—38). The names marked with asterisks indicate plants which are not found in the Labrador taiga. But in general this list contains the same species as Table I above. RAUP (l. c.) also states that park-like white spruce forests are common on the shores



Map. 4. Moisture index map of Canada, according to SANDERSON 1950. Note that the lichen woodlands in Labrador are situated partly in a perhumid region whereas the lichen woodlands in Canada's Northwest are situated in a subhumid region.

of Lake Athabasca. Black spruce seem to be absent from such forests, probably because the area studied by RAUP is dominated by sedimentary bedrock. In Labrador the common Archaean granite-gneiss bedrock causes dominant black spruce lichen forests on dry forested lands; white spruce lichen forests are more common along the rivers.

It should be noted here that there seems to be no particular correlation between the regional distribution of the lichen woodlands and the moisture regions in Canada based on relation of water deficiency to water excess (see Map 4). The lichen forest type is generally considered a xerophyte forest type just as the caribou lichens are considered xerophyte plants. However, the lichens, as also most of the mosses, are more or less independent on the moisture conditions of the soil; they are no xerophytes in the true sense of the word, compare p. 28 below. *It is interesting to note that the lichen dominated park-like forests in Canada's Northwest are situated in a dry subhumid region* (SANDERSON 1950), *whereas the lichen woodlands in Labrador have their main occurrence in the humid and perhumid climatic region in Canada's Northeast* (compare HARE 1950). This points in the direction that the temperature rather than the precipitation is the main limiting factor for the forest types in the boreal forest belt. It is wellknown that the tree growth in the north is more dependent on the variations in temperature than on variations in precipitation (see H 1950, p. 80). HARE (l. c.) has stressed the fact that there is an obvious correlation between the forest divisions and thermal efficiency in Labrador. Compare also KALELA's classification of the boreal dry conifer forests (1944).

The climatic requirements of the lichen woodlands are not easy to determine; we still know too little of its ecology. The main factor in its development seem to be the occurrence of large sandy areas. In northern Europe and Asia the latest glaciation, just as in North America, left behind it large sandy plains, ridges etc. On such habitats lichen woodlands are fairly commonly distributed all over the boreal forest belt. The ecologically well-defined lichen and dwarf shrub lichen forest types have very much the same appearance throughout the boreal forest belt. This means that *studies of similar forest types in northern Europe and Asia could be usefully applied also in Canadian forestry and to its reindeer industry.*

In northern Scandinavia and Finland *spruce* lichen woodlands are extremely rare (see FRIES 1913); this statement is based on literature as well as on the author's own experience and verbal communications from foresters. But *Scots pine (Pinus silvestris) lichen woodlands* are very common in northern Sweden, Norway and Finland and form the basis for the reindeer industry in these countries. The forest botany and ecology of the lichen

woodlands have been studied i. a. by KIHLMAN 1890, FRIES 1913, AALTONEN 1920 and MALMSTRÖM 1949.

In his paper on the vegetation in the Kola Peninsula, REGEL (1937) does not mention Piceetum cladoniosum (spruce lichen forests), but instead Pineetum cladoniosum (i. e. Scots pine lichen forests) and also forest associations like Pineetum empetroso-cladoniosum and Pineetum calluno-cladoniosum a. o. pine dwarf shrub lichen forest types.

In spite of the fact that the tree species dominating the lichen woodlands differ, the ground vegetation in the lichen woodlands of Canada and northern Europe and Asia is very similar. The main point in this respect is, of course, that *the dominating lichen, Cladina alpestris, is the same species all over the lichen woodlands*. Under the crowns of the sparsely distributed pines, crowberry and mountain cranberry occur together with feather moss species, just as in the Canadian lichen woodlands. However, the lichen woodlands all over northern Scandinavia and Finland are extensively grazed and lichen woodlands with 10—15 cm high lichen cover, common in the Labrador taiga, are now rare.

Northern Russia and Siberia have large pine and spruce (and in some places tamarack) lichen woodlands. SOCZAWA (1927) and SAMBUK (1932) describe i. a. Piceetum cladinosum and Cladopiceetum (both spruce lichen forest types) from the northern Urals and Petschora. These spruce lichen woodlands are, of course, of primary importance to the extensive reindeer industry of the natives in the Russian Subarctic. In the southern part of the Taimyr district, between Jenisej and Khatanga, spruce lichen woodlands — very similar to those described from Labrador — are common. To show how similar the dry boreal forest is throughout the northern hemisphere, the following passage is quoted from DEDOV (1933). He describes the spruce lichen woodlands near Jenisej:

»Lichen spruce forests are more often met with on wide plains, more rarely on the slopes of the hills. In the ground cover the lichens are well developed, with dominant *Cladina alpestris*, but also *C. silvatica* (close to *C. mitis;* author's note), *C. deformis* (fairly near *C. coccifera;* author's note) a. o. There are no mosses to any degree worth mentioning. Spruce forests of this type are very open. The trees often stand at a distance of 10 meters or more from each other and their height varies from 4 to 10 meters; a few birches, more rarely tamaracks, are found. In the spruce lichen forests one often finds a great amount of dwarf birch (*Betula nana;* related to *B. glandulosa;* author's note) which here forms a more or less dense bush thicket. The shrub and ground cover is generally very scarce and poor in species» DEDOV (l. c., p. 26 Orig. Russ.).

Fig. 9. The typical branchless part of a white spruce stem in an exposed part of a lichen woodland. Sample plot 8, Great Whale River. Photo I. H. 1947.

This description could well be one of the lichen woodlands in the Labrador taiga. DEDOV (l. c., p. 36 and 35) also mentions more or less pure tamarack lichen woodlands, especially in the Norilsk valley, about 68° north. Lat. The lichen woodlands seem to be scarcer in eastern Siberia; there the large lichen-covered tundra and forest-tundra areas form the basis for the reindeer industry.

The lichen woodlands form a belt between the tundra and the boreal forest region proper. It is one of the commonest collective forest types in the forest tundra region and in the large northern boreal region. There is, however, a very close similarity, not only in the ecology and in the flora, but also in the fauna of the circumpolar lichen woodlands (the caribou and the reindeer, for instance).

IV. On the Ecology of Lichen Woodlands.

Snow-cover.

The height of the snow-cover varies in every forest. The lichen woodland is very open and the snow-cover is usually less deep in the open spaces between the sparsely distributed trees, see Fig. 10. It is fairly easy even in the summer

to discover how high the winter snow-cover generally is on the different habitats; it is indicated by: 1. the height of the bushes, particularly dwarf birch and 2. on the spruce trees in more exposed areas of the lichen woodland there is generally a branchless part (see Fig. 9). The reason for the absence of buds on the spruce stems at the snow-cover height is probably due to the low temperature and the wind on the snow-surface (or to rabbits?). This low temperature at the snow-surface, lower than the air temperature some decimeter above the surface, has been demonstrated by meteorologists; compare KERÄNEN 1920. The low temperature restricts the development of the buds. The bark on the windy side of the stem is usually smoother than on the other side of the trunk. A difference also exists sometimes in the colour of the twigs: the needles under the snow-surface have a light blue-greenish colour, the needles on twigs above the snow-surface have a more clear greenish colour.

The temperature of the snow is, with the exception of the surface of the snow, very uniform at different depths. Thus a thin snow-cover gives the vegetation nearly as good protection as does a deep snow-cover. The importance of the protection given by the snow is evident on open spaces in the lichen woodlands where the low branches of the spruces are more luxuriant than the branches which reach above the snow surface. Fig. 10 illustrates i. a. the varying height of the snow-cover in different parts of a lichen woodland.

There are, as far as the author knows, few investigations concerning the snow conditions in Canada. KLEIN has recently (1949) begun an investigation of the physical characteristics of the snow. With the exception of a Rocky Mountain station the snow-cover depth was greater at Goose Bay in Labrador than at any other station investigated during the survey in 1947. According to KLEIN's graph (l. c., p. 120), the snow-cover depth in Goose Bay on an exposed test area reached in average about 3 feet during February-April 1947.

However, it must be stated here that the snow-cover was unusually deep in 1947 in Labrador, according to statements by Indians at Old Factory and Fort George during our journey in 1947. Mr. LLOYD STROME, a Hudson's Bay Co's employee at Kanacaupischow, about 120 miles inland from Fort George, stated that the snow-cover in some places was 12 feet deep, and that much higher values were occasionally measured in the valleys. The Indians had told the manager at Old Factory that the snow-cover in 1947 reached an average of $4^1/_2$ feet in the country inland from Old Factory; the snow-cover was deeper that year than for several decades before. Thus, the snow-cover depths measured during the Canadian snow survey of 1947 must be considered as maximum values, at least in parts of Labrador. In this connection it should

be noted that an Indian at Fort George said that in winters with rough snow conditions the caribou used to come down to the coast already in the winter. And a snow-cover of 3—4 feet is very deep; generally 3 feet is considered more or less a maximum, at least for reindeers' winter grazing.

Reindeer-grazing in winter is dependent, however, not only on the depth of the snow-cover but also on the »quality» of the snow. Thick ice sheets in the snow-cover — because of repeated thawing and freezing of the snow surface — or a heavy ice crust in the spring are serious obstacles for reindeer or caribou. This subject requires further investigation, particularly regarding the formation of so-called »sevä»-layers (a Finnish word); when new snow falls on old snow which has been thawed by occasional mild weather, a very tough »sevä»-layer is formed after the freezing of the snow. The reindeer penetrates only with difficulty this »sevä»-layer; for further details, compare *Renbeteskommissionen* (1909).

That the conditions in winter-time in Labrador on lichen woodland must probably be less severe for the animals than might be expected from the 1947 snow survey in Canada is, of course, also illustrated by the fact that in earlier decades very large caribou herds grazed in the interior of the Peninsula; compare below, p. 43.

Lichen cover.

According to its degree of exposure to the wind the lichen cover is more or less homogeneous. On the crests of the ridges, on the edges of terraces, on the tops of old dunes etc., now covered with lichen woodland, the lichen cover

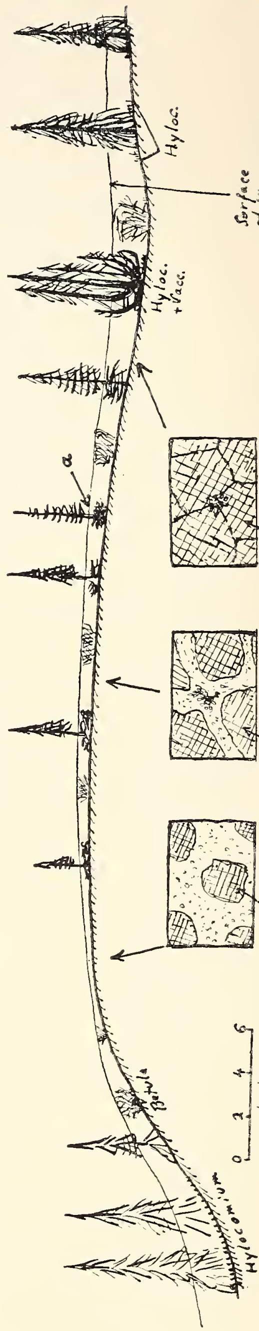


Fig. 10. Sketch drawing showing the different height of the snow-cover and the different tree forms occurring in a lichen woodland. *a* = the branchless part of the spruce trees; see Fig. 9. 1 = exposed lichen cover, 3 = well sheltered lichen cover.

(*Cladina*) forms separate rounded tufts, see Fig. 5. Between the tufts the soil is barren or partly covered with hardy ground lichens: *Alectoria ochroleuca*, *Cetraria spp.* etc. In open lichen woodlands the lichen cover, i. e. mainly *Cladina alpestris*, forms polygonal facets with narrow tracts. In these tracts small lichens (like *Cladonia coccifera*) appear, as do also isolated individuals of crowberry, mountain cranberry, spruce seedlings etc., see Fig. 7. In more sheltered woods, however, the lichen-cover is without tracts in wet weather. But in dry weather (see Fig. 11) the polygonal structure of the lichen cover is still visible. The formation of such polygons in the lichen-cover shows a striking resemblance to the well-known formation of stone and soil polygons on open barren patches in the tundra region, a resemblance which is probably caused by the peculiar mechanism of the freezing and thawing of the ground surface.

The commonest lichen species in the lichen woodlands is *Cladina alpestris* (L.) Web. *C. mitis* Sandst. is very similar to *C. sylvatica* (L.) Haim. emend. Sandst. (both species earlier *C. silvatica* (L.) Hoff.). In northern Europe »*Cl. silvatica*» is probably often *C. mitis;* compare LYNGE 1921. See fig. 12—14.

It seems that *C. mitis* (or *C. silvatica* coll.) is the first reindeer lichen species to invade a burned lichen forest; compare LYNGE 1921, KUJALA 1926a and SARVAS 1937; the author's limited experience points in the same direction. *C. mitis*[1] or *C. silvatica* has a slightly broader ecological amplitude than *C. alpestris* and probably tolerates shadow slightly better than *C. alpestris* (KUJALA 1926 b). *C. rangiferina*[2] has the widest ecological amplitude of the three main reindeer lichens; it also often penetrates into the dry tussocks on bogs. This applies also to *C. alpestris* and »*C. silvatica*» (H 1939, p. 38), but generally *C. rangiferina* is more tolerant of moist habitats than the other

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[1] »Dans les memes habitats que *Cl. sylvatica*» (des ABBAYES 1939, p. 126).

[2] As pointed out above *Cladina alpestris is the true reindeer* (*or caribou*) *lichen*. It is the commonest Cladina species in the northern lichen woodlands. The three main Cladina (Cladonia) species were not earlier taxonomically separated; they all formed »Lichen rangiferinus» (LINNÉ, Spec. Plant. 1753). In his Flora Lapponica 1792 LINNAEUS, however, mentions a »Lichen rangiferinus major», which according to VAINIO (1887) is Cladina alpestris and MICHAUX' »Lichen rangiferinus 2. minor» (Fl. Bor. Amer. 1803). LINNAEUS used the height of the tufts as the basis for his name, MICHAUX, however, probably the size of the twigs of the podetions, see Fig. 14. Michaux' »Lichen rangiferinus 1. major» is Cladina rangiferina, according to VAINIO (l. c.). Because of the complicated taxonomical background there is often a certain confusion in the Latin names of the reindeer or caribou lichens in many papers.

Fig. 11. Large homogeneous *Cladina alpestris* cover, cracked by the summer drought into »polygons». Central Labrador (Ungava) George River valley, about 55° 26′ north. Lat. Photo J. ROUSSEAU 1947.

reindeer lichens. All four species mentioned here (true *C. silvatica* does not occur in the author's few collections from the sample plots) are circumpolar.

C. sylvatica (L.) Hoffm. is found on several localities in the province of Quebec, according to LEPAGE (1949), but *C. mitis* is more common. »Avec le *C. alpestris*, la présente espèce (i.e. *C. mitis*) constitue, dans le Nord, la majeure partie du tapis lichénique servant de nourriture aux caribous. Selon une opinion un peu générale, on attribue ce rôle au *C. rangiferina* qui, d'après nos propres observations et en autant que le nord de Québec est concerné, est bien moins abondant que les deux especes precedentes» (LEPAGE l.c., p. 331).

The reindeer lichens, like lichens in general and several forest moss species are »pollakauophytes» (sensu BUCH 1946); they get their water, and their mineral nutrients with the water, through the cells in the thallus, not through any vascular organs from the soil itself. These *lichens are ectohydrates*, and the vascular plants and many mosses are endohydrates. This physiological difference has great ecological importance. It explains why lichens grow slowly, why they are able to grow on barren sand without humus and why lichens invade the surface of tussocks when the latter loose their connection with the ground water. Because of their physiology the reindeer lichens live many decades, perhaps centuries. In theory the lichens are immortal organisms: the

Fig. 12. A typical cryptogam »profile» through a lichen heath in the Knob Lake area (material from sample plot 10). *Cladina alpestris* above, *Dicranum fuscescens* coll. underneath. To the left a small *Orthocaulis* sp. Scale in cms. Photo S. HOLMSTRÖM.

podetions die at their lower end and continue their growth year after year, but extremely slowly, as is shown on p. 34. The lower parts of the lichen podetions form a very slowly humifying layer, the consistency of which is very loose. (The lichen tufts or »polygons», 40—50 cm. in diameter, are therefore easy to lift from the ground; the lichen in northern Scandinavia is, therefore, collected in tufts which are kept together in big heaps with a stick as winter food for reindeer kept near the house or for cows or sheep.)

The cracking dry lichen cover fast becomes as wet as a swamp after rain. The moist lichens contain 60—70 % water, an airdried lichen 10—15 % only.

Fig. 13. *Cladina alpestris;* note apothecia. Scale in mm. Photo S. Holmström.

Vaartaja (1950 p. 103) noted how a closed dry *Cladina alpestris* cover kept about 60 % of the precipitation during a day in July.

The *Cladina alpestris* cover is exposed to severe changes in the temperature conditions. In an open lichen forest extremely high temperatures can be measured, as can extremely low temperatures also, before the soil is covered with snow. In open lichen woodland the effect of the cooling wind is prominent and added to this the sun radiates directly to the lichen cover. In such microclimatical conditions only the most drought-resistant plants can live. Jalas (1950) gives interesting data on the temperature amplitudes (nearly 40° C between night and day) on lichen heaths in northern Finland.

Together with *Cladina alpestris* one sometimes finds small liverworts but also bigger moss species, usually *Dicranum fuscescens* s. lat., which forms a green cover under the reindeer lichen (Fig. 12). It is difficult to understand the reason for this. Has the lichen penetrated the moss-cover, or is the moss penetrating the lichen-cover? Or is there no question of »succession» at all; the Dicranum is simply growing in the »shadow» of the lichen, which shelters the moss from the strongest radiation of the sun? Also, the lichen-cover certainly decreases the evaporation of the Dicranum moss. One also finds reindeer lichen »penetrating» into a feather moss cover and vice versa. A detailed investigation of this

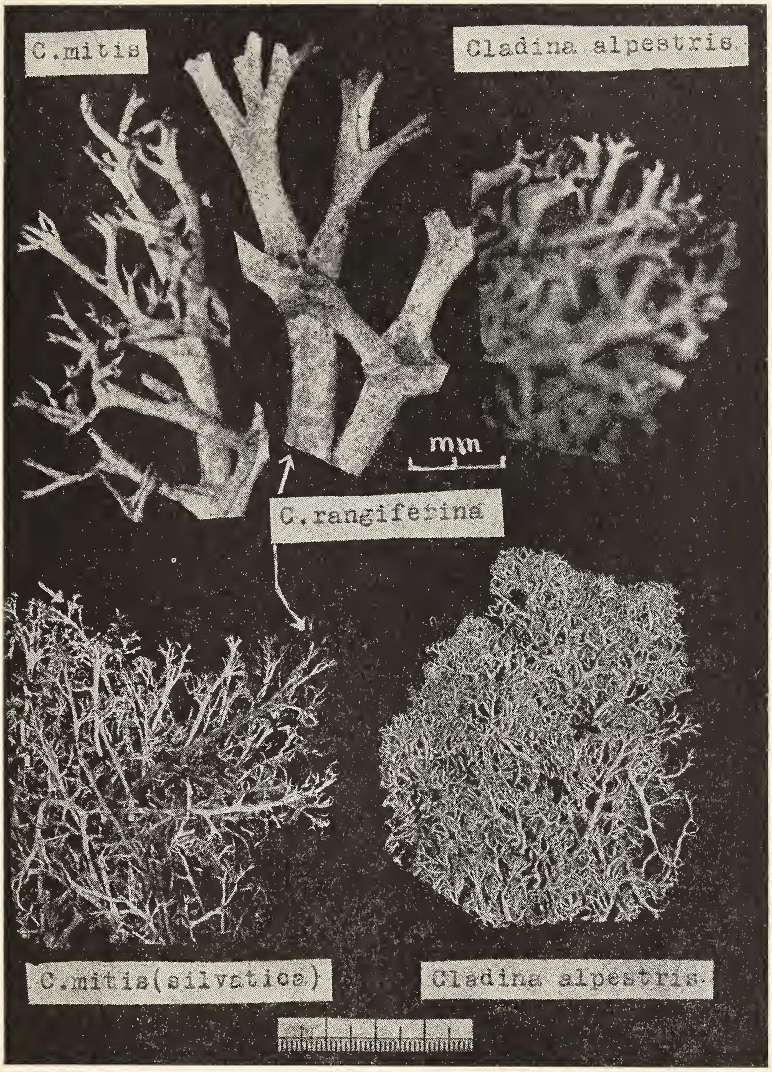

Fig. 14. The three main *Cladina* species in the lichen woodlands. Material from sample plots 1 and 10.

ecological problem should solve the forest-botanical question of the successional stages in the Labrador taiga: is the spruce lichen forest only a primary and pioneer stage in the succession of the forest types in the boreal forest belt, or is it the climax type? Many opinions have been advanced to date, but, to the

best of the author's knowledge, no detailed ecological investigations have been made into this problem.

In lichen woodlands other lichen species (other than the *Cladinae*) are only occasional intruders, except *Stereocaulon* spp. *Stereocaulon* usually seems to stand melting water longer than *Cladina;* one sometimes finds *Stereocaulon* in slight depressions, where the snow-cover has melted late in the spring. *Stereocaulon* is frequently seen (as are also crowberry tufts) on or near old trails through the lichen woodland. *Because of this the old trails are visible long after the last traveller, man or caribou, has passed along them.*

In very exposed areas the reindeer lichen gives way to hardier species: *Cetraria islandica, Alectoria ochroleuca,* etc. In barren patches in the lichen cover *Cladonia coccifera* a. o. species intrude. They seem to be more temporary visitors only, present in the lichen cover when the latter is undisturbed by man or reindeer grazing.

The other lichen species which form the ground lichen cover, *Cladonia gracilis, Cetraria islandica* and others, as also lichens on stones and trees (see below), are all eaten[1] by the reindeer; compare Lönnberg (1909). There seem to be only one type of ground lichen which is not touched by the reindeer: the *Opisteria* (*Nephroma*) and *Peltigera* species. Of these species only *Opisteria arctica* is occasionally seen in lichen woodlands: the other species belong primarily to the spruce feather moss forest type.

Beard Lichens.

Of the pendulous lichens or the beard lichens, the black *Alectoria jubata* is the commonest species in the Labrador taiga. The white *Evernia mesomorpha,* which, according to information from an Indian at Fort George, is much liked by the caribou in winter-time, is common at least along the James Bay and Hudson Bay east coast. Apart from these species the following pendulous lichens seem to be fairly common in Labrador: *Alectoria lanestris*[2], *A. implexa, A. nidulifera, A. sarmentosa, A. simplicior.* The epiphyte and particularly the pendulous lichen flora in Scandinavia and in eastern Canada is very similar. In both regions *Alectoria jubata* and its varities seem to be the commonest species. (It should, however, be noted that *Alectoria Fremontii,* which is very common in the pine lichen forests in northern Scandinavia, seems to be entirely absent from eastern Canada; compare Ahlner; 1949).

The beard lichens occur in all forest types. Only along the Labrador coast

[1] Regarding *Stereocaulon* spp. there seem to be different opinions (Dr. R. Sarvas; verbal information).

[2] Close to *A. jubata.*

do the black beard lichens seem to be rare. But on all his other excursions the author has frequently seen beard lichens in the old forests. Forest scientists have discussed the role of the beard lichens in the forests. It seems that they cannot be regarded as a »disease». The pendulous lichens are distributed by the wind to trees that are already old and sick, and they grow until the infected tree dies, but they are not the cause of the death (ROMELL 1922).

(The many lichen species which grow on smaller twigs, on trunks etc., mainly *Cetraria, Parmelia, Parmeliopsis* species, are of no interest in this connection. They begin their growth as small dots on 3—4 year old twigs and continue their growth very regularly and slowly, as can be seen in a comparison of the annual shoots from different years.)

The beard lichens are of importance as emergency food for caribou and reindeer during winters when the ground lichen is covered by unusually deep snow, or when there are several ice sheets or »sevä»-layers in the snow, or when there is a hard ice-crust on the snow-cover in the early spring. This had already been noted by Richardson 1829 in NW Canada. In such years the reindeer herders in northern Scandinavia and Finland cut lichen-covered trees as emergency fodder for the reindeers; the average for one reindeer is perhaps 100 trees in one winter, or 2—10 trees a day; compare ITKONEN (1948).

Green Fodder in Winter.

Table I shows that several herbs and grasses occur as minor constituents in the lichen woodlands. The buds, shoots and some green leaves of these plants give the reindeer or caribou green fodder, i. e. proteins, in the winter. The protein content of lichens is not very high; compare analyses on p. 45. It is wellknown that the reindeer eats the green parts of herbs and grasses, but the author has found only one quantitative estimation of the amount of such »green fodder» in the reindeer's winter diet. According to AVRAMCHIK (1938) the reindeer in the Yamal tundra eats 65 % lichen, 33 % phanerogams and 2 % mosses in the winter. A compilation of older Scandinavian investigations appears in LÖNNBERG (1909); see also *Renbeteskommissionen* (1909).

V. Regeneration of the Reindeer Lichen.

It is a well-known fact that the reindeer lichen grows very slowly. In the field this can be partly judged from the height of the lichen on burned areas. In one case, for instance, near the east coast of James Bay, the reindeer lichen cover (*Cladina mitis*) was only 1 inch high on a pine dwarf shrub lichen forest

which had been burned about 25 years previously, see Fig. 6. But on such localities usually other cryptogam species, e. g. the pioneer mosses, grow faster on the newly burned raw humus; reference is made to investigations by KUJALA (1926a) and SARVAS (1937). A lichen forest grazed by reindeer or caribou herds recovers more rapidly. There are several instances in the literature referring to the number of years the lichen cover requires to recover: 3—7 years (LÖNNBERG 1909), 6—15 years (ITKONEN 1948), 10—20 (40) years, (LYNGE 1921), 15—20 years (RÄSÄNEN 1928), 15—30 years (TENGVALL 1928). The big differences are caused by the varying opinions held as to when a lichen cover can be considered as »recovered». ITKONEN mentions (l. c., p. 82) that according to some Finnish Lapps a lichen-cover height of 2—5 cm is enough to allow new grazing on a lichen field. After a fire the recovery of a lichen field is slower, 40—50 years (ITKONEN l. c.), 30 years (MANNING 1946), 30—40 years (SARVAS 1937); see below. In Rokuanvaara in northern Finland, where lichen is collected for export (as material for wreaths), a complete recovery of *Cladina alpestris* heaths is said to take about 80 years (Dr. J. JALAS; verbal communication).

The regrowth of a lichen field is dependent on the capacity of prolonged growth — apically — of the lichen podetions. Generally (compare SARVAS

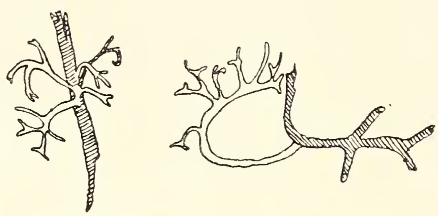

Fig. 15. The recovery of the growth of a *Cladina rangiferina* podetion after a forest fire 8 years ago. SARVAS 1937.

1937) the lichen-cover is not completely destroyed after a fire (see Fig. 3): inside the lichen cover several podetions may preserve their growth capacity, see Fig. 15. Fructification or growth with the aid of soredions is rare in reindeer lichens. The distribution is chiefly by wind of small parts of the podetions. (Note how easily the lichen podetions are broken in dry weather by tramping boots.)

The height reached by a reindeer lichen-cover is primarily dependent on how little the habitat has been disturbed. The author has noted about 18 cm as the maximal height of a lichen cover. DEDOV 1933 reports 25 cm from the Norilsk area near Jenisej, and PORSILD (1929) the same height from the Great

Bear Lake area. In such places the lichen must have been undisturbed by grazing or fires for at least 100 years. DES ABBAYES (1939) gives as maximum heights for the podetions: *Cladina alpestris* 18 cm., *C. silvatica* 15 cm., *C. mitis* 10 cm., *C. rangiferina* 15 cm.

The annual growth of the podetions is slow. TENGVALL (1928) studied the annual growth of *Cladinae* in northern Sweden:

Cladina alpestris	1—2 mm.,	max.	4	mm.
C. silvatica	2—3	»	5	»
C. rangiferina	3—4	»	6	»

The annual growth of *Stereocaulon* was 3—4 mm., but in certain cases 9 mm., which partly explains why *Stereocaulon* seemingly more easily invades »new land» in lichen areas then the *Cladinae*.

IGOSHINA made an extensive study of the growth of *Cladinae* in northern Ural. She noted that the forest lichens grow more rapidly than the tundra lichens. 15 mm. of the upper part of the reindeer lichens represent the zone of most intense growth. »The age of podetium is equal to the number of its nodes hence the average annual growth of podetium could be counted by division of the height of podetium into the number of its nodes[1]» (1938, p. 28).

Recently ANDREJEV (1946) has studied the annual growth of reindeer lichens, using a very large material, about 5,000 measurements. He noted that the growth of the lichens varies according to their height, i. e. their age (air-dried specimens):

Height of *Cladina* species:	Annual growth:
15—25 mm	2.98 mm
26—40	3.25
41—60	3.55
60—	5.17

These values are thus higher than the values obtained by TENGVALL and it is, of course, natural that the annual growth varies according to the local climate and habitat. According to ANDREJEV (l. c.) a 5 cm. high *Cladina alpestris* podetion grows 4.7 mm. annually, a *C. silvatica* and *C. rangiferina* podetion of the same height grows 4.9 and 5.9 mm. respectively, annually. In the arctic tundra *C. silvatica* grows an average of 2.6 mm. annually, in the subarctic tundra 3.4 mm., in the hypoarctic taiga (= probably a sparsely

[1] »Nodes» clearly visible on Fig. 13 and 14.

wooded taiga) 4.1 mm., and in the subboreal northern taiga region 4.6 mm. annually.

*

The complete recovery of a 5 inch high lichen cover in the Labrador taiga after a fire must take a very long time. If it is assumed that the above values of the annual growth of a lichen podetion are also strictly applicable to the northeastern Canadian lichen woodlands, complete recovery requires at least 40 years, probably much more. If the fire has been a strong ground fire, pioneer moss species (*Polytrichum piliferum, P. juniperum, Pohlia nutans* and others) invade the area — in Labrador as in northern Scandinavia — and thus the regrowth of the lichen cover takes a still longer time.

But recovery of lichen cover in the reindeer industry means not only recovery after forest fires, it also means recovery after the winter grazing of a large herd. In that case the recovery is, of course, much more rapid, as the above-mentioned observations also indicate. The reindeer usually eats only the tops of the lichen. The growth of the podetions begins, therefore, immediately. However, judging from the present condition of the lichen pastures in northern Finland, it appears that 3—7 years (see above) will not suffice to keep the winter pasture in good condition. A »rotation period» of 10 years seems, according to verbal communications from reindeer owners in northern Finland, to be much more appropriate.

VI. Forest-economic Importance of Lichen Woodlands.

The economic value of the lichen woodlands in Labrador is often limited. These forest types can hardly be used for any output of timber or pulpwood. The trees are scattered and generally low. 24—36 feet seems to be the average height of spruce in the lichen woodlands. The diameter is mostly about 6—7 inches; it can, of course, attain slightly greater proportions, rarely 10 inches with black spruce and about 15 inches with white spruce. The spruces are usually branched to the ground, except, as pointed out above, in more exposed parts of the forests, i. e. crests of ridges and terraces, open slopes, at higher altitudes etc., where the snow-cover line is visible on the trees. The candelabrum-form of black spruce is, from an economic point of view, of little interest: only the central stems reach pulpwood size and their cutting is tedious. It should also be noted that in the northern part of the taiga, where pulpwood can be taken, the growth period is short. Thus, the time during which the

Fig. 16. Section at the ground of a slowly grown white spruce, about 30 feet high and 150 years old. From lichen forest at Great Whale River. The section shows features generally characteristic for black spruce (H 1950).

pulpwood can be barked is short, generally about two months only: the cambium growth begins at the end of June.

On one hectare of lichen forests there are an average of 100—200 trees of pulpwood size; the cubic yield of one hectare is probably about 10—15 cubic meters. The growth in thickness is small: reference is made to Table II, which roughly illustrates the average annual growth in thickness during the last 10 years of trees on lichen woodland. It should be noted that on such habitats not only black, but also white spruce grows slowly. The growth in height of the mature black and white spruce in lichen woodland is as a rule 1—3 inches only. Diagrams 3—4 in H 1950 illustrate the growth of black and white spruce in the Great Whale River area. The material is chiefly from lichen woodlands. The annual cubic growth on these lichen woodlands varies, but it is almost certainly about the same as the annual cubic growth of the badly grown pine forests in northern Finland, i. e. about 0.25 cubic meter per hectare. Another obstacle for foresters in the lichen woodland is the slow growth of the seedlings in the lichen cover. Diagrams 1—2 illustrate the relation between

Fig. 17. Black spruce lichen forest with occasional white birch in the Goose Bay area in Newfoundland-Labrador. Photo F. K. Hare 1947. By courtesy of the *Royal Canadian Naval Photograph.*

age and height of spruce seedlings in the Great Whale River area and in the Knob Lake area. The age determinations were made with a microscope. A large percentage of the spruce seedlings on such localities show a very depressed growth, they are bushy and deformed and sometimes frost-injured.

All these facts show that, from an economic point of view, lichen woodland must thus be considered unimportant. For local building timber and fuel demands the lichen woodlands can be used. The pulpwood shortage in eastern Canada will have to be very acute before the lichen woodlands in the taiga are invaded by the pulpwood companies to any great extent. It must also be observed that large parts of these lichen woodlands lie outside the area of

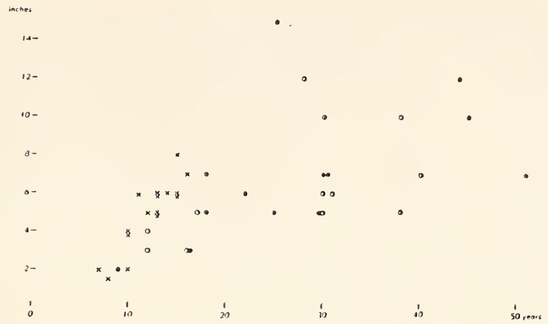

Diagram 1. The correlation age to length of 41 white spruce seedlings from 3 different sample plots of lichen woodlands in the Great Whale River area. (1950).

accessible forests: the rivers in the entire western and northern part of the taiga flow into Hudson Bay and Ungava Bay, as can be seen from Map 3.

One more point: if a lichen forest is cut, it is usually a long time before the area is covered by forest again. The rotation period is slow in the northern parts of the taiga — at least 100 years. Also, a cut lichen forest might easily turn into a barren and exposed lichen heath, where arctic-alpine plant elements intrude and make spruce reproduction still more difficult. Many burned forest areas in Labrador are now entirely barren and show no signs of turning into

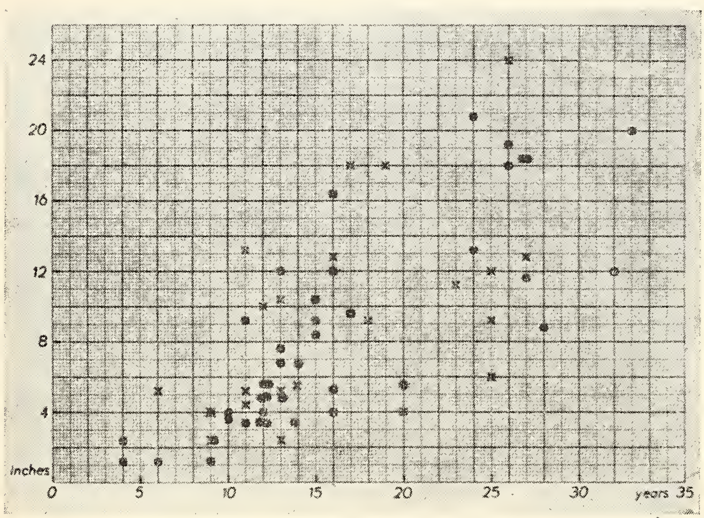

Diagram 2. The correlation age to length of 66 spruce seedlings (dots = white spruce, × = black spruce) from a lichen forest near Lake Gillard in the Knob Lake area in Central Labrador.

woods again; compare H 1939. On other earlier burned areas a forest may perhaps grow again, but it does not attain the same size or commercial value as before. This does not apply only to Labrador; it is a general observation also in other 'subarctic' forest areas. The recent climatic fluctuation, in the twenties and the thirties, at higher latitudes, has partly saved the situation, but the effect of this climatic fluctuation has, according to the author's observations, been less marked in Labrador than in northern Scandinavia.

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Considering these circumstances it seems that the best use which man could make of the vast lichen woodlands in Labrador is primarily as winter pasture for domesticated reindeer. The use of lichen woodlands in forestry must be limited to local timber and fuel.

VII. Capacity of the Labrador Lichen Woodland as Winter Pasture for Reindeer.

The Cladina species are the main winter food of the reindeer. If the area covered by lichen woodland can be estimated, the approximate capacity of these areas as winter pastures could be ascertained — if the approximate fodder requirement of one reindeer for one winter are known.

The lichen woodlands represent only a part of all the lichen-covered areas in the Labrador Peninsula. There are vast lichen-covered areas in the tundra region. However, the domesticated reindeer generally grazes in the woodland in winter. When estimating the number of reindeer which can feed in Labrador it is, therefore, safe to limit calculations to the forest-tundra or the forested region only. As mentioned in H 1949, the approximate area of lichen woodland in Labrador is about 40,000 sq. miles, spread over a forest-tundra region which covers about 130,000 sq. miles and through the taiga region which covers about 280,000 sq. miles compare map 1. Lakes and rivers take up a large percentage of this area. The interior plateau of Labrador is, as is probably less known, richer in lakes than perhaps any other part of North America.

How much lichen does a reindeer eat in one winter? Some interesting studies have been made in northern Scandinavia and in Russia and Siberia. Soczava puts »the annual maximum requirements for 1 reindeer (what it will eat and trample) as 5 tons of normal humid lichens and 0.7 tons of green forage (counted as hay)» (1933, p. 113). Lynge (1921), a Norwegian lichenologist, states that the best localities give 1,400—1,500 kg. of lichen per 1,000

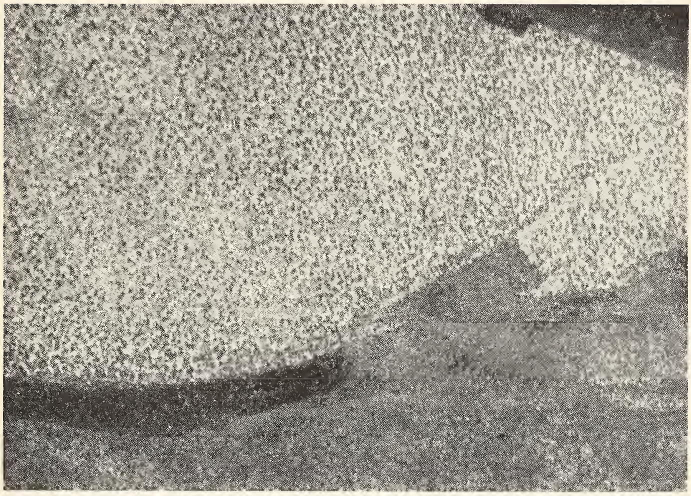

Fig. 18. Aerophoto showing the spruce (probably black spruce) lichen forests near Susan River in the Hamilton River area in Newfoundland-Labrador. Photo V. TANNER 1937.

sq. m., i. e. 14—15 tons per hectare. LYNGE himself says that this is an absolute maximum value. A Russian estimation (DEDOV 1933, p. 35) calculates for a 5—6 cm. high lichen cover a weight of about 2.5 tons per hectare; this is probably a good average value. Old mountain lichen heaths of Yamal give 5—7 tons lichen per hectare with an annual increase of about 400 kg; poor lichen grounds give 1—1.5 tons per hectare (IGOSHINA 1938). In all cases probably normal humid lichen is implied, i. e. lichen as eaten by the reindeer in winter-time.

Now, using the values obtained above:

1. there are about 10.5 million hectares of lichen woodland (i. e. about 40,000 sq. miles) in Labrador,

2. the amount of lichen on one hectare is about 2.5 tons,

3. the reindeer eats about 5 tons of lichen annually,

4. the rotation period of a lichen field should be about 10 years to keep it in good condition (see p. 36),

the following conclusion can be drawn:

Considering these facts and that the percentage of trampled lichen (useful the following winter) *is roughly about the same as the percentage of non-lichen cover in the lichen woodland, the Labrador Peninsula has good winter pasturage for at least 0.5 million reindeer.*

It is perhaps of interest to make an estimation based on the total area required by one reindeer according to previous reports in the literature.

An old Finnish government report (1905) assumes that 200 reindeer require an area of about one Swedish sq. mile, i. e. about 50 hectares per reindeer. In northern Finland there are about 5—10 % lichen woodlands according to the last national forest survey.

PORSILD estimated (1929) that in NW Canada on the arctic coast about 24 hectares (= 60 acres) are needed for one reindeer, but in the Great Bear Lake area the pastures are better, only some 16 hectares per reindeer. This estimation is in close agreement with some Russian calculations. The carrying capacity of a good winter range area, about 1 million hectares in Norilsk near Jenisej, is about 50,000 reindeer; an average of 20 hectares per reindeer (DEDOV 1933, p. 41). GORODKOV estimated (1933) that in the Russian Far Eastern Province the capacity was 5.5 million reindeer on 964,500 sq. km., which makes an average of 18—19 hectares per reindeer. In the Far Eastern Province »the reindeer capacity is limited by the pasture territory of the summer use» (l. c., p. 163). SOCZAVA (1933, p. 114) concluded, on the other hand, that the »lichen forage will determine the limit of saturation by reindeer in the Yakutsk tundra». He estimated that 389,000 sq. km. in Jakutia could carry only 700,000 reindeer, i. e. about 55 hectares per reindeer. STEFANSSON estimated once that Alaska could support 4 million reindeer (the whole area is 1.5 million sq. km.), i. e. about 38 hectares per reindeer. Considering the nature of Alaska this was a very optimistic estimate, as has been proved recently (LANTIS 1950). Note also ILLINGWORTH 1949 regarding introduction of reindeer in Scotland.

If it is taken

1. that the whole area of the Labrador forest-tundra and its taiga region is 410,000 sq. miles and

2. that at least 75 hectares is needed in this area rich in lakes for one reindeer, about 1.5 million reindeer could be grazed in Labrador. However, the very conservative estimate on p. 41, based on the area of lichen woodlands, probably gives a better picture of the situation, considering also the present activities of the mining and lumber companies.

In these calculations no account has been taken of the potential area of summer pastures. As mentioned above, the area of suitable summer pasturage limits the reindeer industry in the Russian Far Eastern Province. It looks as if the winter pastures should be comparatively better than the summer pastures in many areas in the interior of Labrador. From this point of view the more

cautious of the two estimations of the carrying capacity of the lichen woodlands is preferable.

A positive factor in this connection is the scarcity of caribou in Labrador. Earlier large herds of caribou trailed through the wilderness. According to several recent observations (TANNER 1944, MANNING 1946, POLUNIN 1949) the caribou is now rare in Labrador. In the George River and the Great Whale River area only 3—4 caribou were killed during the winter of 1946—47 according to information received at the HBC-posts. At Knob Lake in central Labrador, in August 1948, the author was told that only one caribou had been seen during the year. In some parts of the forest-tundra, however, there are probably more caribou; compare WHEELER 1930.

From the air many caribou trails through the lichen woodlands can probably be traced. But these trails are generally old. The regrowth of the lichen is very slow, as mentioned above, and other lichen species or dwarf shrub species often invade the old trails. Such »clear trails» remain visible in many parts of the woods long after the last caribou traversed the forests in the area.

The scarcity of caribou partly explains why the lichen woodlands in Labrador are generally so clean and homogeneous. The lichen woodlands in Labrador seem at present — on the whole — to be the best winter ranges for reindeer in the whole of North America and Europe.

*

In Finland 100 reindeer per person are usually reckoned as a guarantee for comparatively good living in the wilderness in northern Finland. About 500,000 reindeer should thus provide a living for 5,000 persons (natives), which is approximately twice the whole native population in Labrador today [1]. The future mining centres in Central Labrador and on the North-Shore are potential great consumers of reindeer meat. The reindeer industry also gives the

[1] The wellknown expert on northern Canada, Mr. A. E. PORSILD, Chief Botanist in Ottawa, has made the following comment after reading this paper in MS: »I think you are perhaps right that reindeer could be raised very successfully in parts of Ungava. One difficulty however would be the deep snow of the interior winter range, which I think would be a very serious problem. The most serious however, as elsewhere in Canada, is that there are not enough people anywhere in Canada who are willing to take up the work as reindeer herders, and I am afraid that any natives that a few years ago might have been willing, have now been spoiled by a taste of civilisation and too high a standard of living» (in letter of April 19th, 1951).

natives full compensation for the diminishing hunting possibilities resulting from the northward move of the big lumber and pulpwood companies and by the erecting of new mining centres.

A reindeer herd increases with good tending by about 40 % annually. The reindeer herds in Alaska came to 143 animals in 1893, in 1903 795 animals, according to JACKSON's report to Washington 1905 (quoted after LÖNNBERG 1909). In 1938 the Reindeer Service in Alaska (after LANTIS 1950) estimated a total of 600,000 reindeer in Alaska. Considering the possibilities for better regional planning in the sparsely-populated Labrador taiga, it might be possible to increase an introduced reindeer herd of 250 animals to about 500,000 animals in 20 years.

Appendix.

The Nutritional Value of the Reindeer Lichen.

It should be remembered that the reindeer lichen is a good additional fodder for hardy cows and sheep in the north. as experience and experiments in northern Europe have shown.

The nutritional value of the ground lichens, particularly *Cladina alpestris*, need no further comment. The species *Cladina rangiferina* is not, in spite of its name, the species preferred by the reindeer (a well-known fact recently pointed out i. a. by des ABBAYES 1939). In northern Scandinavia and Finland *C. alpestris* is the common »reindeer moss»; *C. alpestris* is also the commonest species in the Labrador lichen woodland.

Colonists in northern Finland have used reindeer lichen since olden time as additional fodder for their cows and sheep. It is mixed into the hay, about one third lichen and two thirds hay, particularly in years when the harvest from the meadows is abnormally small. It has also been mixed into the rye and barley meal in unfavourable years in Finland. In the last decades — as is well-known — the antibiotic value of lichen acids has been investigated; compare VARTIA (1950) and literature quoted by him.

Miss LAINA RÄSÄNEN has studied the chemistry of *Cladina alpestris* (1947). According to her the mineral percentage of this species is 0.8, the water content of the lichen, when dried at 100—105° C., is 9.8% and the etherial oil content about 0.1 %. The nitrogen content, determined according to Kjeldahl's method, was 0.72 %, i. e. about 3.7—4.5 % proteins.

The nutritional value of the lichens is dependent on their carbohydrate content. V. RÄSÄNEN (1928) analysed the nutritional value of some lichen species:

Table III. Nutrients in some lichen species.

Species	Water	Nitrogen	Proteins	Minerals
Cladina alpestris	0.7	0.72	4.53	3.6
C. silvatica	5.1	0.61	3.79	2.5
C. rangiferina	5.0	0.67	4.18	2.95
Alectoria prolixa (= jubata)	9.7	0.66	4.14	1.0

Table IV gives another analysis of reindeer lichen by the Norwegians Isaachsen and Ulvesli (1933):

Table IV. Nutrients in reindeer lichen.

	Dry matter	Organic matter	Crude protein	Digest. crude protein	Fat	N-free extract	Crude fibre	Ash
Total nutrients ..	34.6	34.0	1.0	—	1.0	17.6	14.4	0.6
Composition of dry matter	100	98.3	2.9	—	2.8	50.9	41.7	1.7
Digestible nutrients ..	(20.7)	(20.4)	—	0.7	0.6	9.8	9.3	0.3
Digestible nutrients in dry matter.	(59.9)	(59.2)	—	2.0	1.6	28.5	27.1	0.7

The amount of protein is not very great and according to the above-mentioned authors it is more or less indigestible (l. c., p. 723).

Recently Presthegge (1944) made experiments in Norway regarding the utility of lichen as additional fodder for animals, cows, sheep and pigs. He concludes that lichen is very useful as (carbohydrate) fodder for animals which have earlier been accustomed to a lichen diet; the digestibility of organic matter in lichen was 57 % (the digestibility of protein matter in lichen was negative). The percentage of carbohydrates in the dry matter of lichens is 93—94 %. 100 grammes of dry matter of *Cladina alpestris* contains, according to Presthegge, 98.7 % organic matter, 2.5 % crude proteins, 2.1 % fat, 52.9 % N-free extracts and 41.2 % crude fibres; compare Table IV. The ash contained, in this analysis, 0.08 % calcium and 0.02 % phosphorus.

Literature.

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ON THE GROUND WATER CONDITIONS

IN THE

CANARY ISLANDS

AND THEIR

IRRIGATION CULTURES

BY

H. HAUSEN

WITH 18 ILLUSTRATIONS IN THE TEXT

HELSINGFORS 1951

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Preface.

The author has devoted nearly a whole year (during journeys in 1947, 1948 and 1950) to geological and volcanological studies in the Canary Islands, especially in the island of Tenerife. In the course of my work I found many occasions to be more familiar with the special ground water conditions governing this Archipelago and with the means adapted here to the search and the recovery of the water, seriously required for the use in irrigation of the sub-tropical and tropical cultures in the coast regions of the islands. These studies lying outside my special task, were made possible thanks to the courtesy of several persons engaged partly in the search of water and in the various technical works connected with its extraction, partly in the plantation administrations. To all these Gentlemen, especially to Mr Ulrique Ahlers (Finca Agua Dulce, Tenerife), Mr S. Benítez Padilla (Las Palmas, Gran Canaria), Mr J. Morell Delgado (Santa Cruz), Mr J. J. Mugica Aramberría (Santa Cruz), Mr Donato Cabréra (Puerto Cabras, Fuerteventura), and Mr Eugenio Rijo (Arrecife, Lanzarote) I wish here to express my sincere acknowledgements.

The impressions collected during my field excursions were afterwards completed by data from the literature (see the bibl.). The scope of this paper is to characterize the special conditions of ground water occurrences in a volcanic region, much reminding of those governing the Hawaiian Islands in the middle of the Pacific and likewise situated at sub-tropical latitudes under the influence of trade-winds. The mode of motion and gathering of the subterranean water is so totally different from that met with in most of the European countries that a stranger visiting the islands for the first time with the intention to form some opinions of the ground water problems, is feeling quite bewildered. There is nothing more capricious in the world than a ground composed of volcanic lavas and ejecta!

Physiography.

The volcanic masses of the Canary Islands rise from an ocean floor lying in the W at a depth of ab. 3000 m, and in the E (between the African mainland and the easternmost island) of less than 2000 m. The islands are arranged into a row, extending E—W but with a slight bow facing with the concave side to the N. The number of the islands is 7, but to these may be added some small rocky islets in the extreme NE, the so called *Islotes*. The total area of the Archipelago is ab. 7617 sq. km (a figure somewhat different by different authors). — The western islands are all lofty with steep sides and coasts dangerous to approach. Gran Canaria has, however, some lower coastal strips, although the central part is lofty. The culminating point of the whole Archipelago is Pico de Teide in Tenerife, 3711 m. The eastern islands are relatively low.

When studying the surface conditions of the Canaries one will find them vividly varying even in one and the same island. We cannot enter here into more detailed descriptions, but some more outstanding features may be mentioned.

The islands are as said above of volcanic origin, and the volcanic constructive forms dominate the landscape with some exceptions. But there are also exogene forces at work: the weathering, the running water and the ocean surf. In reality we find here an eternal struggle between the endogenic and the exogenic agents. Because the volcanic outbursts have ceased in many of the islands already long ago, the erosion has advanced here considerably. This is true especially regarding the island Gomera, the relatively oldest one of the western islands. But turning east we find the big island Fuerteventura representing a very old land-surface too, being of more advanced maturity. The same could be said of Lanzarote, the NE: most island, were there not many new superimposed volcanic cones.

If we turn our attention to the exogene surface forms, we find that they have been created by the vigorous action of the run-off in the winter time, by mechanical and also by chemical weathering under subtropical conditions. And lastly the continuous marine abrasion especially along the coasts of the windward side of the islands has been of the most obvious influence: not only has the circumference of the islands been changed but the gradient of the *barrancos* has been made steeper by shortening of their longitudinal profile. — A special feature of these islands are the so called »*calderas*», wide amphitheatre-like depressions appearing in the more central parts of some islands. A closer

examination of these *calderas* will reveal that they cannot all be of the same origin. In reality more than hundred years ago this theme has been discussed, and the question is as it seems not yet definitely settled. The largest of all the *calderas* is the famous Caldera de las Cañadas in the central part of Tenerife, which is a collapse-caldera, thus a purely volcanic phenomenon. Regarding the other calderas it seems that those of La Palma, Gomera, and Gran Canaria are chiefly erosion forms due to the wildwater in combination with the weathering and the action of the springs. Caldera de Taburiente in La Palma is probably an exception: endogenic forces have assisted here too. The same can be stated about the large semi-caldera on the NW coast of Hierro — El Golfo, having a diameter of ab. 15 km. It seems to be the result also of semi-circular fractures: one half of the island has disappeared into the ocean.

While the surface forms in the western islands have very steep sides dissected by *barrancos* and valleys, but with some remnants of an old weathered upland surface in the culminating parts, the eastern islands are much lower with a rolling relief and broad open valleys and also plains in some parts, lying not very much above the sea. This relatively flat surface is, however, in Lanzarote crowded with younger volcanoes — long rows of symmetrical cones — without any central volcanic mass.

A very conspicuous feature of the Canaries is their scarceness of a loose sedimentary mantle, Alluvial flats are nearly absent. The only more even ground is formed by young volcanic ashes or lapilli. The soil of the islands is generally an *in-situ*-product of the weathering processes and in many tracts where relatively late volcanic outbursts have occurred, the soil is completely absent (»*malpaises*»).

The vegetative cover is extremely varying owing to topographical, climatological (micro-climatological) and other causes. Along the coasts sub-tropical and tropical cultures treated in this paper are to be found. Moreover many tropical trees and plants are to be seen in the gardens there, introduced from all parts of the world's low latitudes. Somewhat higher on the slopes there are many foliferous trees and above these the *pinár* is met with. It consists of the endemic conifer, *pinus canariensis*, forming a distinct forest-belt surrounding the highest part of the islands (at least Hierro, La Palma and Tenerife). Gomera has a forest of *laurus* occupying its highland surface which mostly lies in the clouds. In Gran Canaria the forest has been very devastated, so that only some remnants are left. The eastern islands, Fuerteventura and Lanzarote, are nearly completely barren, except some groups of palms at the bottom of the more sheltered valleys. Their nature is very similar to that of the adjacent parts of Africa.

As we will find later on the forest-belt mentioned above is very important as a moisture condenser: the trade-wind clouds lie mostly in contact with the trees in the zone of altitudes ab. 1000—1700 m.

Climatic conditione.

Regarding the fact that the Canary Islands are situated between the Latitudes 27° 37′ and 28° 24′ N. L. the climate, and especially the temperatures are as known, very agreeable, being to some degree of a maritime character. When comparing the islands with the adjacent Sahara Desert, one will note a great difference. This is due chiefly to two facts: to the Canarian Ocean Current flowing through the Archipelago in southerly direction, bringing cooler water from higher latitudes, and secondly to the northeasterly, northerly and northwesterly winds blowing the greater part of the year. During the winter months there are occasional storm winds from other directions, but generally the winter is very agreeable too, especially in the coastal lands. This fact is chiefly due to the insignificant changes of temperature from summer- to winter time. Other conditions are, however, met with in the high mountains; where winter snow is by no means rare, as in Pico de Teide and Las Cañadas in Tenerife, and occasionally in the highlands of Gran Canaria.

The climate of the Canary Islands being of the outmost importance to the study of the origin and circulation of ground water, is still not so well studied as in many European countries. Permanent and complete observation stations in the islands are very few, and only one of these has been in function since the sixties of the last century (La Laguna in Tenerife). But the meteorological study is making rapid progress, since many new stations in the later decades have been organized.

Regarding the temperature Santa Cruz (Tenerife) has an annual mean amplitude of only 6.4° C and Orotava lying on the north side of the island, only 6° C. Likewise Las Palmas lying on the low NE-coast of Gran Canaria has an amplitude of 7° C. Going up the mountain slopes one finds naturally other conditions: the annual amplitude increases (for inst. the Observatory Izaña, in Tenerife lying at an altitude of 2367 m has a difference of 13° C a mean figure). Extremes are in the high regions very great. In the basin of Las Cañadas, Tenerife, at an altitude of ab. 2000 m winter temperatures down to —16° C have been observed. Also on the southern slopes of the islands, especially in Tenerife and in Gran Canaria the climate is more excessive, a fact which may be understood when regarding the wind regimen of the islands.

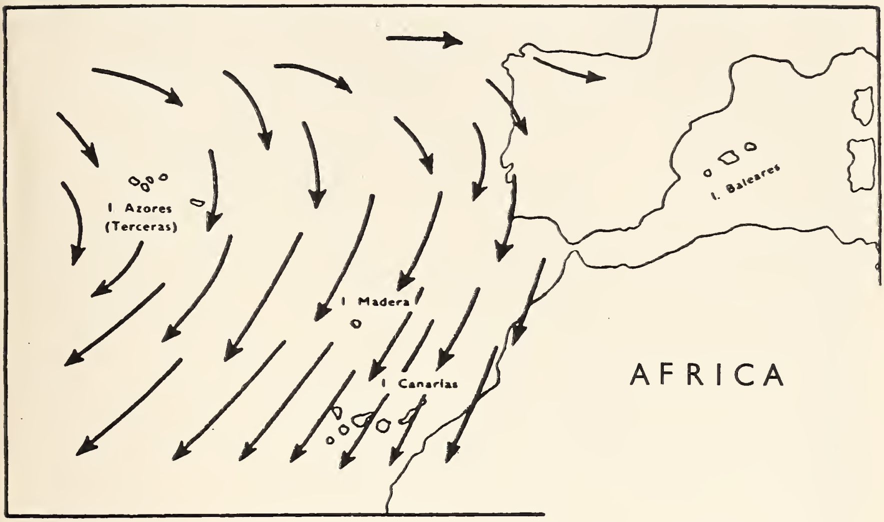

Fig. 1. Sketch map showing the general directions of the trade-winds during the summer season over the eastern Mid-Atlantic region.

As already said the Canaries are nearly the whole year under the influence of the northerly trade-winds. The islands have, therefore, a marked windward and a leeward side (*barlovento* and *sottavento*). This situation is most obvious in Tenerife whose longer axis lies in a direction crossing that of the dominating wind. But also La Palma and Gomera and Gran Canaria have their windward sides. In the eastern islands where the relief is, as has been said, considerably lower, such climatic regimen is absent. The winds blow over the whole islands and mostly with great violence.

Interruptions in these trade-winds occur when the hot and dry gale called »*el levante*» suddenly appears, blowing from the third quadrant and bringing the dust-loaded air masses out from the Sahara. This wind raises the temperature to an excessive height for a time — generally it lasts but for some days.

During the winter season exceptional winds of a stormy character also appear, due to perturbations in the atmospheric currents of wider extension over the Atlantic. Cold air masses from higher latitudes are carried down to the Canaries, mostly arriving here from the W (»*el palmero*») and bringing heavy rains and on the upper mountains even snow and hail. During such *temporales* the peaks are snow-clad, and this snow-cover may last for many days and also for weeks.

The atmospheric precipitation is generally speaking quite insignificant in the Canaries, but it is unevenly distributed regionally as well as seasonally.

Fig. 2. An expressive witness to the constancy of the northern wind in Tenerife: *Eucalyptus*-trees in inclined position standing along side the high road from La Laguna to Mercedes. Photo by the author 1950.

As in the Mediterranean regimen the winter months are the season of rains; whereas the long summer (and the early autumn in addition) is very dry. The different islands have, however, quite varying conditions in this respect.

When the trade-winds approach the lofty western islands of the Canaries, the air masses are forced upward along the slopes to cooler regions. The humidity of the air is, therefore, condensed to a cloud cap, lying nearly every day during the warmer season at altitudes of ab. 800—1700 m, rarely up to 2000 m (see the pict. fig. 3!). This cap brings shadow to the windward sides protecting the ground from a too rapid evaporation of its moisture. In the upper regions the cap causes sometimes a fine rain, but generally the moisture is condensed directly from the fog in contact with the forest trees and the long needles of the conifers (esp. *pinus canariensis*). There is a constant drop of water under the branches of the trees, and this water percolates immediately into the soil.

Above the upper limit of the cloud cap the landscape is entirely different: the forest has disappeared and a vegetation of bushes, sparcely strewn over the barren lava ground is met with. There is in Tenerife the Cañadas-region with the Pico volcano; in Gran Canaria we have the barren highlands between

Fig. 3. The cloud cap in the N slopes of Tenerife in the summer season. Pico de Teide to the left. The upper surface of the cap is ab. 2000 m above the sea (record). From a post card.

the Caldera de Tejéda and Caldera de Tirajána, the culminating point being Pozo de Nieve (1970 m). Likewise in La Palma there is a similar highland ground reaching above the forest zone to > 2000 m surrounding the Caldera de Taburiente in the middle of the island.

Gomera makes an exception because it is lower: a forest mostly of laurel covers the highland, except where deforestation has taken place. In this island no part reaches above the cloud cap.

In the central regions of Tenerife and Gran Canaria above the clouds there dominates a very dry weather during most part of the year, with an

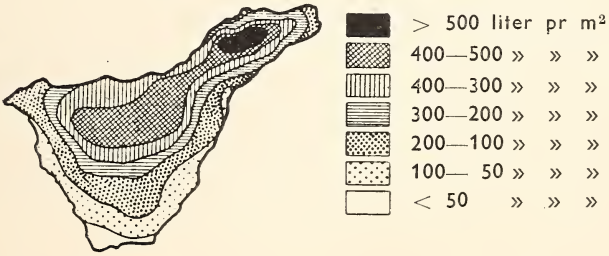

Fig. 4. A pluviometric map of Tenerife (annual means). From Banco de Vizcaya, Rev. financiera, Islas Canarias, Año 19, N:o 76. Bilbao 1950.

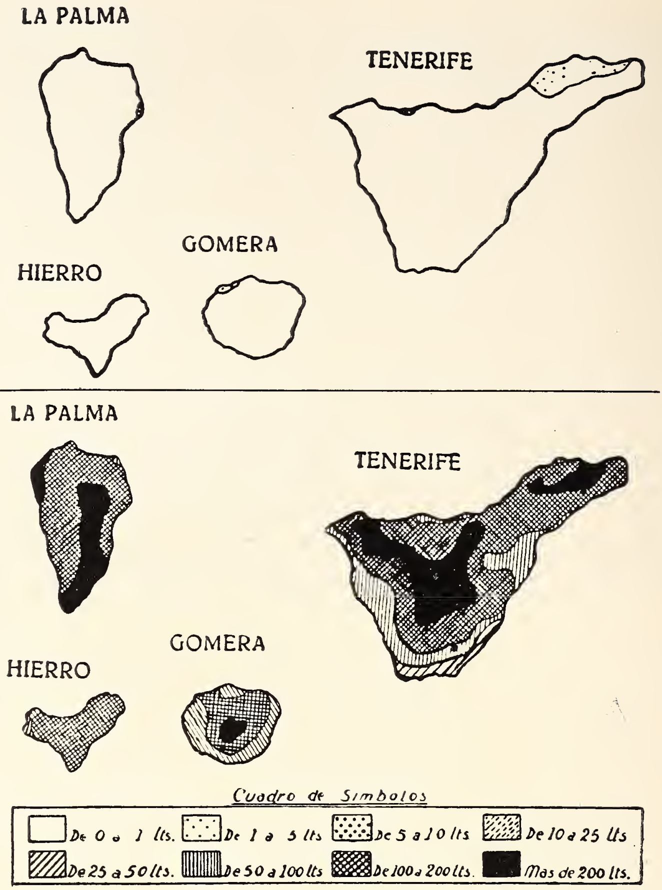

Fig. 5. Pluviometric maps of the western group of the Canaries showing the rainfall during the months of July (upper part) and March (lower part) in the year 1949. The two maps indicate the great difference in rain quantity of the two seasons. Boletin mensual del Centro Meteorologico de Tenerife 1949.

intense insolation from a cloudless sky, and no wind is met with, except in the winter months during the occasional atmospheric disturbances which as has been said can bring rain and snow for some time.

The trade-winds do not reach the highlands as we have seen. On the uppermost peaks we note an air current, coming from the south and known as the »antipassat».

The windward side of La Palma, Gomera, Tenerife and Gran Canaria represent, consequently, the humid regions, where rain occurs also in summer. On the other hand the leeward side (or *sottavento*) is as has been said very dry,

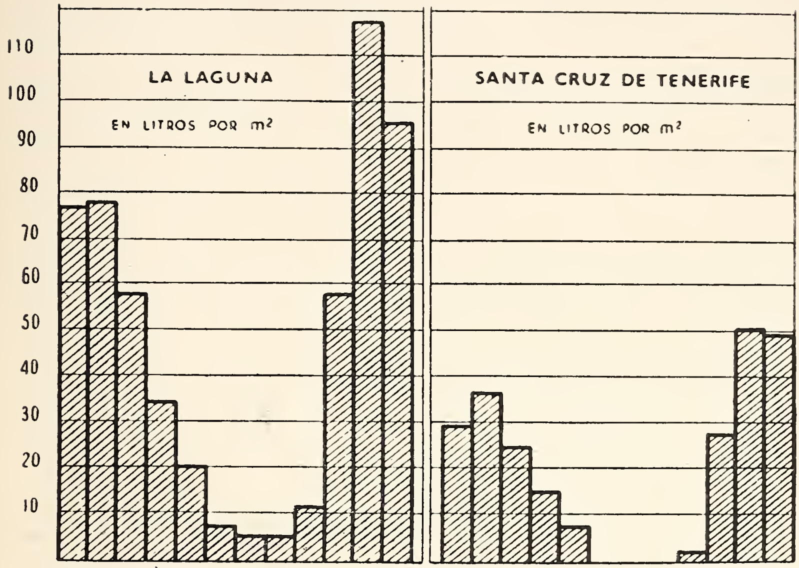

Fig. 6. Diagrams showing the marked seasonal changes in the rainfall amount in two cities of Tenerife: La Laguna and Santa Cruz (litr. pr sq. m, mean fig.)[1]

desert-like regions, and only on the upper slopes of the mountains there is a greater amount of precipitation, especially during the winter-*temporales*. In the last mentioned regions we find consequently also a forest zone, reaching to the upper limit of the clouds.

The monthly and the annual rainfall are now known from all the islands according to observations from a great number of stations, but the series available do not comprise any long time with some exceptions referring to the older stations. This fact is a handicap in getting an exact idea of the real amount of rain (and snow), because the seasonal amounts are highly varying from year to year. We may here quote some figures available:[1]

Santa Cruz (Tenerife)	annual	amount	243.8	mm
La Laguna »	»	»	568.4	»
Orotava »	»	»	409.5	»
Guimar »	»	»	206.4	»
Izaña »	»	»	420.3	»

[1] From: Boletin mensual del Centro Meteorologico de Tenerife, and Banco de Vizcaya, Rev. financiera, Islas Canarias, Año 19. No. 76. Bilbao 1950.

Valleseco	(Gran Canaria)	....	annual amount	790	mm
Terór	» »	....	» »	526	»
Tenteniguáda	» »	....	» »	456	»
Gáldar	» »	....	» »	154	»
Las Palmas	» »	....	» »	144	»
Mogán	» »	....	» »	78	»

Stations on the leeward sides of the two islands are Guimar and Mogán, the former being not very typical. It is remarkable to find a very low

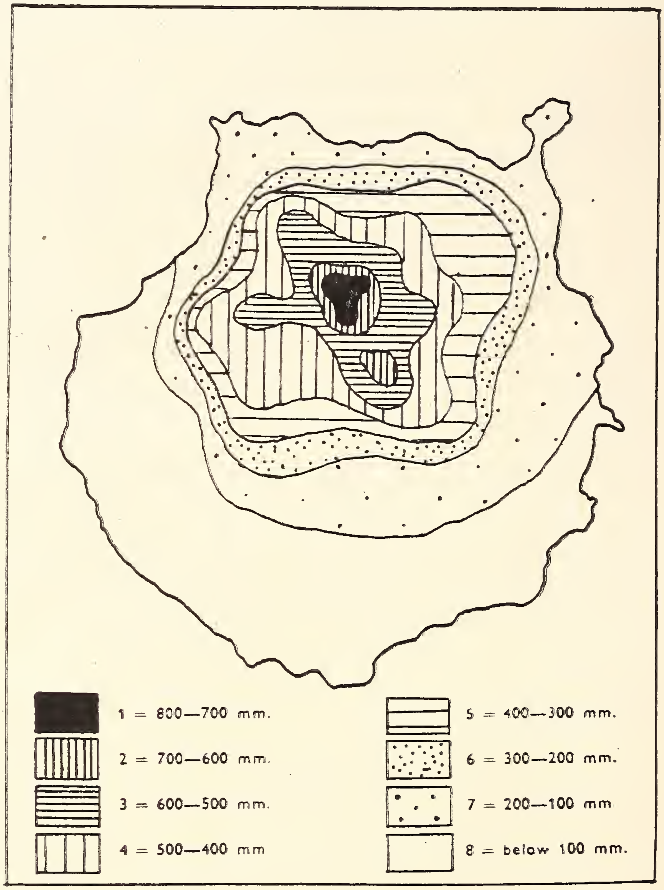

Fig. 7. Pluviometric map of Gran Canaria. Banco de Vizcaya. Revista financiera. 1950.

figure for Las Palmas, although this city is on the windward coast. In fact this spot lies far outside the cloud cap.

The figures quoted are of different value, and they can be considerably changed from period to period, as the annual variations are great, and likewise the variations from one series of years to another. — No figures from the other islands are at my disposal. Hierro and the eastern islands would show very low annual amounts.

The above quoted figures of the annual rainfall reflect essentially the precipitation of the winter months with one maximum in November and another in February-March. The rains are mostly heavy and of short duration. Thence no permanent rivers can be maintained in this climate, except some valleys on the windward sides where spring-water is exceptionally abundant (Valle Hermigua, Gomera and also Barranco de las Angustias, La Palma).

During a stay in the winter 1950 in the region of Buenavista, Tenerife, the author experienced a typical torrential rain, lasting for some days. The *barrancos* were suddenly filled with a roaring flood of dirty water plunging in falls down the coast. A dry canyon crossing the village of Buenavista and descending from the 'Caldera de Palmar', was in a night changed to a little »Niagara». But after the rain had ceased, the torrents rapidly dwindled away, and the former typical silence regained the mountains.

The rock ground and its degrees of perviousness.

As already mentioned the Canary Islands represent with some exceptions an assemblage of lofty volcanic edifices, piled up from the ocean floor. In details the structure of everyone of these islands is quite complicated, and we cannot enter here into any comprehensive description. Only the general features of their geology may be touched upon, especially those of a greater significance regarding the behaviour of the subterranean water.

Speaking in general terms the islands show, when we leave the easternmost islands out of consideration — a distally dipping structure, every one having a common orographic, geologic and hydrographic center. The bedding is caused by a great succession of lavas of different kinds with many intercalated tuff and ash layers, scoriae and agglomerates. The piles of such layers are generally dissected by dikes and by the many conduits or feeding channels of the »parasitic» cinder cones on the slopes.

The eastern islands, Fuerteventura and Lanzarote, do not belong to the general scheme sketched above. The former is an old plateau with a mature

erosion surface, the latter has undergone volcanism without any dominating center: the orifices are spread over the whole island.

The lava rocks are of very different kinds; we have picrite basalts, olivine basalts and feldspar basalts, with or without amygdaloid varieties. Further there are (among the more recent lavas) basanites and tephrites, trachytephrites and trachybasanites, andesites, phonolites, trachyphonolites and trachytes and lastly — in Gran Canaria — also rhyolites, all with many transition members.

These lavas are generally very permeable, due to the abundance of joints and cracks and elongated vesicles and channels of tube-like shapes, formed during the flow of the lava. Very common is a columnar jointing with the prisms standing perpendicularly to the surface of the corresponding lava sheet. In other cases, as in the phonolite beds a platy exfoliation can be observed combined always with steep or vertical cracks.

The most easily permeable rock members are the beds of scoriae at the base of nearly every lava sheet. These beds are highly porous and are as we will see the leading 'horizons' of the ground water motion, especielly when they are underlain with impermeable tuff-layers.

In their superficial parts the volcanic masses are intensely mechanically weathered, and the disintegration has naturally created a highly permeable ground.

The volcanic lavas do not appear exclusively as more or less concordant sheets. A great deal of the protruded masses fill tectonical fissures and faults and have been chilled in them. Volcanic dikes are very characteristic in the Canarian rock ground. Their extension, relative frequency, and common directions have still remained unfixed. Also the petrography of the dike rocks is only locally more known. In every case these dikes are of great importance as far as the motion of the ground water is concerned. Many of them act as dams which store the ground water into compartments in the higher regions of the islands.

Many types of dike rocks have already been described in the literature. Also the author will soon (as he hopes) contribute somewhat to their knowledge as far as Tenerife is concerned. In this connection we may deal only with some more outstanding types having importance in the ground water regimen. On the one hand we find the basaltic dike-rocks. They are quite dense in their texture (aphanites), but show a distinct parting into prisms lying transversal to the saalbands. It is clear that they do not form any effective obstacle to the water movement.

Another group of dikes show a platy parting parallel with the walls of

the dike, the rock being mostly a phonolite or trachyte. This kind of dikes forms very effective curtains against the water motion. Likewise may several of the dense and un-jointed dikes be of the same effect.

As already stated one may find the dikes in abundance in the higher mountains of the islands, and a general tendency is an orientation along the main axis of the mountain ridge as is the case for inst. in Anaga and in Cumbre de Pedro Gil in Tenerife. In such cases the dikes form a rift zone as it may be called. Other dikes cross this trend in different directions. In such a way the dikes may form more or less closed compartments, and if there are in the older lava ground some impermeable tuff layers, the ground water may be stored, so that the water table of such a compartment may occur at a high level.

Naturally all the rocks and also the dikes are permeable to some degree. In the long run there is a leakage of stored water and the stand of a compartment's water table depends on the leakage and on the inflow of fresh water from above.

Very important regarding the ground water regimen are the more or less weathered tuff layers between the lava sheets. These fine grained pyroklastics have at one time formed the surface of a certain region and been exposed to the weathering. The tuff has been altered to a »*terra rossa*»- like lateritic soil of considerable impermeability, being a ferruginous clayish product. The avenue of motion of the ground water stream is thus confined to the upper limit of an altered tuff layer, or more particularly explained to the hanging scoriaceous sheet. Regarding the fact that several more or less impermeable tuff layers appear in the pile of lava sheets, there are many separated streams of ground water to be expected.

A very porous rock is a kind of *puzzolane*, a cream-coloured or whitish »*tosca blanca*» of great thickness, being an consolidated mud flow of phonolitic composition. This rock occurs chiefly in the southern part of Tenerife and will be mentioned in the following.

Large areas in the Canaries are covered with various kinds of loose ejecta, black, brown, reddish, yellowish, and white materials consisting chiefly of lapilli. These lapilli-fragments are partly of compact lava partly of pumice. The fragments are sometimes cemented together by lime or a ferruginous matter.

All these kinds of loose material, mostly stratified, are very porous and absorb quickly the rain water. They have, moreover, the advantage of preventing the evaporation of the percolating water and are — especially the black lapilli-masses — very adapted to the vine culture.

If such lapilli strata occur at levels below the surface, they form excellent ways of motion for the ground water streams.

The water in motion. General principles.

After having studied the different members of the rock foundation of the Canaries regarding their ability to absorb the ground water and control its motion and percolation down to the lower levels we may now devote some pages to the water itself.

a. Run-off.

As already mentioned the rain water (and the melting snow on the mountains) seeks its way sometimes superficially along the bottom of the *barrancos.* Although in ancient times there existed in the Canaries perennial rivers or streamlets in the valleys, none can be observed in our days, except during heavy rains. That a greater humidity of the climate existed in former days is out of the question. This fact may be seen also from the important records of the running water in all parts of the islands. These testimonies would be still stronger if the repeated volcanic outbursts did not tend to destroy the exogene surface forms by filling up the *barrancos.* About the real causes of this desiccation in progress the author has not seen any explication. Perhaps the destruction of the forest-belt lying at levels corresponding to those of the cloud cap of the trade-winds has to some degree provoked the decreasing humidity. But there may also be some climatic causes outside the Canaries.[1]

Due to the steepness of the bottom gradient of the *barrancos* the stream-power of the intermittent rivers is great and prevents many times the construction of storage dams. It is only in Gran Canaria that this method of recovering the atmospheric water is practized to wider extension, as we shall see later on.

Consequently the surface water hurling down the slopes in times of the heavier (winter-) rains is generally lost. But to some degree it percolates into the bottom of the *barrancos* and the valleys and changes into ground water.

b. *The underground water.*

Far more important for the irrigation purposes is the ground water in the Canaries, recovered in many ways as we shall find later on. There is a constant

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[1] In periods corresponding to the North-European Ice Age the rainfall was apparently greater, as may be seen from the former extension of the laurel-rain-forests in the islands.

flow of the subsurface water from the central, highest regions of the islands down to the coasts — a centripetal motion.

The migration of the subterranean water is going on the whole year — likewise in the long dry season — and the ultimate base is of course the ocean level. The rate of motion is in every sector naturally somewhat different due to the changing degree of permeability. And the intricate structural conditions make the directions of the motion capricious. The greater retardations in the motion of the water cause underground storages at altitudes where such ones may not be expected.

High level ground water perched by impermeable tuff layers and stored by volcanic dikes.

If the islands consisted of a more or less homogeneous mass of eruptive material of great permeability, all the ground water would accumulate at very low levels, attainable by technical means only in the peripherical parts of the island — the coastal regions. Fortunately the conditions are partly of another kind: a considerable part of the percolating water is perched already at higher levels — in the alpine regions, thanks to the occurrence of intercalated tuff-layers in the lava ground. These layers being mostly altered to a clayish product — are relatively very impermeable preventing the water from passing straight downward. The water is forced to take its way down the slopes according to the general dip of the stratification. Partial leakage in the tuff layers creates the repetition of this motion at still lower levels, so that a number of super-imposed ground water streams can be formed.

But in the higher mountain ridges there are, as we have seen, often abundant volcanic dikes steeply inclined and crossing all the semiconcordant volcanic strata. They act as impermeable walls preventing the further motion of the ground water. The latter is stored in compartments in these high regions.

Naturally none of these dikes is exactly impermeable. Leakage occurs continuously so that a circulation really takes place. The dam only retards the latter. — Every compartment has its own ground water level, whose height depends on the rate of inflow from above and on the rate of leakage. The former stands naturally in connection with the amount of precipitation, so that in winter this level lies higher than in the dry summer time.

The presence of these ground-water-filled interdike compartments is of the utmost importance to the irrigation cultures. Expensive drillings and pumping in lower regions are avoided, and the water in question (taken by

way of tunnels) is of good quality. The high level ground water lies far above the ocean water, the latter impregnating the basal ground with its cracks, fissures and pores.

Centripetally moving ground water following the impermeable tuff beds between the lava sheets.

The part of the ground water which has not been stored behind the dikes in the rift zones of the islands moves further down the slopes as already mentioned. The water forms generally not one but several streams following separate tuff layers.

These impermeable layers are, however, in most cases not even and rooflike. They undulate and they end many times suddenly sidewards or downwards. In many regions a survey of the ground will reveal the existence of old valley bottoms covered with the impermeable tuff material and afterward filled with new lava flows. In such buried channels one may find good ground water streams.

The breadth of the front of any ground water stream moving slowly down to the coast may be very variable. A great disadvantage to the development of a broad and abundant ground water stream is the presence of deep *barrancos*, dissecting the water bearing layers. These *barrancos* are most intensely developed in the middle heights of the island slopes. Further down the slopes the conditions may be somewhat better.

Springs in the slopes.

When walking along the *barrancos* of the higher slopes one observes here and there a great abundance of springs, generally issuing at the upper limit of an impermeable tuff layer between lava sheets. These springs manifest the presence of ground water streams moving in the interior of the ridges separating the *barrancos* from one another. Taken as a whole the springs represent a considerable leakage of the ground water in an island. In former times the springs were the only places from where the population in the dry season could recover the drink-water. In our time the quantity delivered by these springs is far from sufficient for the irrigation, while the domestic demand trusts to the new canals and storage-tanks built in the populated regions.

Many times the presence of a spring at the bottom of a *barranco* has provoked the starting of a tunnelling operation for the search of a ground water stream in the interior of the mountain. We shall later on discuss the tunnelling developments more in particulars.

A great number of springs, more or less well known in the different islands could be enumerated here, but we had better return to this matter in another chapter.

Basal ground water table.[1]

Ground water moving downwards through the pile of rocks composing an island and reaching the level of the surrounding ocean encounters salt water in the pores and cracks. This percolating fresh water has naturally a lower specific gravity than the salt water and floats upon it. A layer, or better a flattened body, of fresh water is formed known as the b a s a l g r o u n d w a t e r. The water table formed at the top of this body of fresh water has a certain gradient: it rises slowly inland from the coasts. The gradient depends on the relative permeability of the percolated rocks and naturally on the amount of downward moving water supplied from above. The slope in question is practically horizontal in most cases. The fresh water body floating on the salt water displaces the latter to an amount inversely proportional to the difference of their specific gravities. Consequently the rise of the water table inland is accompanied by an increase in thickness of the fresh water layer. This behaviour of fresh water resting on salt water in a permeable rock complex such as the case may be in the Canaries is known as the GHYBEN-HERZBERG Principle, and it has been found widely applicable to volcanic islands, in the first time to the Hawaiian Islands by W. LINDGREN. a. o. For every foot the water table stands above the ocean level the base (the bottom limit) of the fresh water body will be approximately 40 feet below N. N. — In reality the limit between the fresh and the salt water is not sharp due to an admixture of the former with the latter, so that a zone of transition will be formed (a zone of brackish water).

In the direction to the coasts the fresh water body thins out into a wedge. Here (along the coasts) the thickness is consequently insignificant and the water seldom fresh.

Certainly there are great resources of basal ground water in the deeper part of every island, its low position preventing, however, the recovery, except in the coastal regions, where the water table can be reached by borings or by digging shafts. But the water in such places is as has been said in many cases brackish — it has been mingled with the ocean water partly due to a very small inflow of ground water from the interior or to a too intense pumping

[1] The statements below partly quoted from the Report on the Geol. and Ground Water in Molokai, Hawaii Islands (1947), where the conditions are quite similar.

in the well. If the well is situated very near to the sea shore, there may be some influence of the tide-water turbulence, causing a salt water addition.

In the relatively low easternmost islands the conditions are somewhat different from those sketched above, but we may postpone these things to a later chapter.

The central volcanic heat and its bearing on the ground water conditions.

As is known there is still some volcanic activity — although with long intervals — in the Canaries. At least in three of them we can note outbursts in 'historical time' (comprising ab. 450 years), the latest occurring in June-August 1949 in La Palma. It is clear that concerning the still »active» or »latent-active» islands we must take the interior volcanic heat into consideration when studying the ground water possibilities. The question is of greater interest only regarding Tenerife, and thence we may enter into this discussion later on. At the moment it may only be stated that the presence of volcanic heat in the interior of an island must have its influence on the percolation and the storage of the water at higher levels. Below the geotermal surface of 100° C which may lie quite near to the superficies of the island the water changes into steam which seeks its way upward again. The intense evaporation on the surface typical to the heights above the clouds (due to the insolation) takes away the rising water to some degree, except in those places where the steam not being condensed, issues in the fomaroles or solfataras (Pico de Tide, Montaña del Fuego, Duraznéro) i. e. in the still »active» centers. The strong rise of the geoisoterms round the volcanic core and their steep gradient round it is in some near lying regions of an unfavourable influence to the tunnelling operation as we shall see later on.

Special conditions in the different islands.

After having studied the general conditions regarding the ground water possibilities in the Canaries we may now enter into a more detailed treatment of every-one of the islands. For a more comprehensive description of them the author has, however, not sufficient material. He is trusting partly to personal experiences partly to the more recent publications quoted in the bibliographic list. In spite of the fact that so many eminent geologists have visited these islands, the more detailed knowledge of their geology is still very insufficient. Not one geological map to be used for practical purposes can be overcome! The Canaries are still awaiting a modern thorough geological survey and mapping.

Fig. 8. A part of the N side of Caldera de Taburiente, La Palma, showing the distinct stratigraphic boundary between the old basement of the island and the superimposed volcanic formation. The corresponding plane is an important aquifer. Photo by the author 1948.

La Palma. — This island of ab. 730 sq. km lies in the extreme NW of the Archipelago. It is a huge mass of chiefly volcanic lava sheets but in the center there is a core of deep-seated plutonic rocks exposed in the famous Caldera de Taburiente. In the walls of this caldera one can see a very distinct limit between the old basal complex and the covering younger lava formation. (Pict. fig. 8.).

There is a great number of springs in these walls and most of them issue from the structural surface mentioned above. The flow from the springs is abundant, so that the outlet from the gigantic kettle, Barranco de las Angustias, has a perennial flow, the only »river» existing in the Canaries!

The water issuing from the springs seeks its way, as has been said into the bottom of the outlet-*barranco*. But a considerable part is recovered already in the walls and slopes, and is conducted by long canals to the fertile land of Los Llanos de Aridane, a gentle slope on the western side of the island. All the plantations here are furnished with irrigation water from the *caldera*.

The island in question is a good condenser of the moisture brought by the

trade-winds, which affect the eastern sides and the northern broad declivities. But also the western slopes receive much moisture from the occasional westerly winds in the cooler season, so that the coniferous forest zone is quite well developed all round the island. The runoff may sometimes be strong enough and in the summer (September) 1949 shortly after the volcanic outburst in the ridge Los Rancones, heavy showers on this ridge washed away the loose ash-sediments recently deposited. Then the water-saturated ash-mud was swept down the *barrancos* causing severe damages on the automobile road which follows the slopes in the forest region. — The many settlements lying on both sides of the Los Rancones-ridge obtain their domestic water from the springs. — In the SW part of the island there is the famous cavern »Niquiomo» with a spring of very clear water. — In Mazo (E side) there are 6 springs, farther N in San Andres y Sauces 18 springs. Near to the capital Santa Cruz 8 springs and 2 shafts are registered, in Tijarafe (NW side) 4 springs and 13 shafts etc.

Hierro. — This island is as already pointed out relatively prejudiced respecting the ground water resources. The island being of a very asymmetrical outline due to the presence of the giant amphitheatre-like embayment on the NW coast — El Golfo — has a superficie of only 280 sq. km. It is crowned by a comparatively level ground lying at altitudes of somewhat more than 1000 m but dotted with extinct cinder cones. The bulk of Hierro is a huge pile of basaltic lavas with scoriae, tuffs and ash-beds, forming the remnant of a great dome (K. von Fritsch). A very conspicuous feature in the morphology is the nearly complete absence of *barrancos.* A comparison with the near lying Gomera makes this fact more striking. One may assume that the runoff in Hierro since ancient times has been insignificant. Although the climate here as has been said is very dry, it may nevertheless be supposed that superficial water has been in action here. But the erosion forms created have to a great deal been buried under later volcanic material.

Hierro was in former times covered with a luxuriant forest growth, and still in our days there is — although limited — a coniferous forest conserved in the central part of the island. The climate has apparently here (as elsewhere in the Canarias) changed to a drier one. This drought has, however, in the recent decades become so accentuated that the question arose (in 1911) if it would be better to take away the whole population. — There are no water shafts in the island, and the only water to be used is the rain-water caught into tanks during some showers in winter.

Deep borings to investigate the possible accumulation of ground water at higher levels along the crest-line of the island have not been undertaken.

From a theoretical point of view it may be supposed that such a storage exists, because the rock ground is crossed by numerous dikes (seen for inst. in the walls of El Golfo), and impermeable tuff layers are likewise present.

G o m e r a. — This island reminding of Gran Canaria (on a smaller scale) measures 380 sq. km. It is a quite high dome, flat-topped —; the highland lying 1000—1400 m above the sea. As was said the sides are all dissected by deep *barrancos*, on the windward side also by »*caldera*»-like valley-engulfments: Valle Hermigua and Valle Hermoso. The island consists partly of phonolitic lavas, partly of basaltic sheets in a great succession. L. FERNANDEZ NAVARRO the late famous explorer in Canarian geology, considered the former rocks to be the relatively older ones and to form the core of the island.

The water regimen was not more closely studied by the author, but it seems that many analogies can be found with that of Gran Canaria (see below!).

If the conception of NAVARRO is the right one, it may be supposed that the ancient superficies of the phonolitic (or trachytic) core of the island is more or less impermeable and that the ground water percolating from above may be perched by the soil, covering this surface. Moreover the rock ground is dissected by numberless dikes in many directions, which may confine some water at higher levels. But no borings have been effectuated and no tunnels have been opened in the mountains. That there is a constant flow of ground water towards the coasts is seen from the numerous springs in the walls of the *barrancos*. — The basal ground water can be reached by wells or shafts in the lower part of the valleys, but not along the steep coasts.

The wind regimen is very similar to that of Gran Canaria and the rain is relatively abundant in the windward valleys already mentioned. Here perennial streamlets existed some decades ago, as for inst. in Agulo and in Valle Hermigua.

T e n e r i f e. — This, the largest and most centrally situated one of the Canary Islands, has an area of 2352 sq. km with an asymmetric circumference. The greater part of the island lies above the 500 m level and a great deal also over 1000 m. The geological composition is very complicated. It has been investigated by the author in recent years and he hopes to present a comprehensive memoir on the subject in the nearer future.

Without knowing the geological structure of the island it will be very difficult to understand the ground water regimen here. Thence it is necessary to present some general outlines.

As stated already by earlier investigators the oldest parts of Tenerife are the peninsulas of Anaga and Teno being the NE and NW corners respectively,

and further some more isolated erosion mountains in the southernmost part of the island. In all these mountains we find a marked erosion relief in a complex of chiefly basaltic rocks and their tuffs and agglomerates. The »skeletal» appearance is an indication of the advanced age of these parts of the island.

Upon these »corner stones» there rests an enormous mass of somewhat younger volcanic materials building up the central part of the island. First we have the lofty Cumbre de Pedro Gil, a ridge reaching up to 2400 m height and forming the orographic prolongation of the Anaga peninsula towards SW. Then there is the old central dome volcano of Las Cañadas, the summit of which has long ago collapsed forming the famous Caldera de Las Cañadas, an elliptical basin of diam. 20×12 km. Inside this basin there rises the younger twin volcano Pico Viejo — Pico de Teide, the latter attaining as has been said nearly 4000 m ab. the sea. — While Cumbre de Pedro Gil consists chiefly of a pile of basaltic lavas, the central dome volcano of Las Cañadas is composed of phonolitic rocks with subordinate basalts. Both complexes are intercalated with numerous layers of ash and tuffs more or less altered, and they are all dissected by innumerable dikes of steep inclination. These dikes have different orientations but a dominating one runs parallel with the general trend of the mountains. We have here consequently rift zones with deeply reaching tension fissures filled with lava.

The central volcanic apparatus of later ages, the Picos, is composed of mostly glassy phonolites and trachytes, to a great deal solfatarized.

When Pico de Teide ceased to eject lavas and pumice is not known. The crater is still in the solfataric stage.

All the lava sheets and the intervening tuffs etc. are inclined toward the coasts — both in Cumbre de Pedro Gil and in the old dome-volcano. Weathering and erosion have strongly affected the mountains, but not to such a degree as is the case in the above mentioned peninsulas.

From the central volcanic apparatus as well as from many hundreds of parasitic cinder cones on the slopes of the island a great amount of lavas has poured ut, covering the old lava ground and filling the *barrancos* in many sectors. Several of these streams are already quite old and weathered to some degree, others are of a fresh aspect, although no traditions exist to tell when they were erupted. Also very lately — in the eighteenth and the twentieth centuries lavas from scattered cones have issued, the last eruption occurring in the year 1909 (Chinyero). Apart from these lavas, forming *»malpaises»* the eruptions have ejected huge masses of stones, bombs, lapilli and ashes. The pyroklastics originated in the Pico volcanoes are pale-coloured pumice lapilli,

accumulated chiefly in the nearer surroundings, while the 'parasitic' cones have produced black or dark brownish »*arenas negras*» (»black sands»).

The southernmost lower regions of the island (*Bandas del Sur*) are underlain with a mighty formation of a puzzolane rock of considerable consistency. It is cream-coloured and very porous; every pore being occupied by a small pumice fragment embedded in a yellowish water-soluble powder. The rock is entirely unstratified but it is divided into blocks by vertical jointing. — Chemical analyses reveal a phonolitic composition. — The author thinks that this rock was originally a mudflow from the ancient central phonolitic volcano.

The puzzolane is of considerable thickness — up to 100 m and more, but it is mostly hidden beneath later lava outpourings and ash layers, soil cover, etc. — The rock may be considered as an important aquifer.

River- and lacustrine sediments are very rare on the island. They are of no importance as aquifers, except in the small basin of La Laguna.

Now we may examine the conditions of the ground water.

The wind regimen with the northerly trade-wind which dominates the greater part of the year brings relatively much moisture to the northern slopes, as already mentioned. The maximum of rainfall is to be found on the N side of the Anaga mountains (the region of Tegina), as we have seen from the pluviometric map (fig. 4). In the other parts of the island the conditions are very different as known. The most important fact is that the N coastal strip has, although on the windward side, relatively little rain, while the moisture is concentrated on the upper slopes. Here the high level ground water has its domain.

We shall find in Tenerife a quite marked zone or a s t r e a k o f h i g h l e v e l g r o u n d w a t e r beginning in the Anaga peninsula and running along the crest line of Cumbre de Pedro Gil over the the southern Cañadas mountains and further through Talus de Bilma to the Teno peninsula. Moreover there is some perched water also in the Tigaiga mountain block N from Pico de Teide, and lastly the upper parts of the valleys of Orotava and Icod (being broad »sector grabens») contain much high level water.

In this long zone the conditions are, however, changing. The Anaga peninsula in as stated above intensely dissected by the valley erosion and only sharp ridges have been left between the valleys. We cannot expect to find here any mountain bulk with greater capacity to store high level ground water, although the dikes are numerous. On the other side there are numerous springs on the wet N slopes.

In Cumbre de Pedro Gil, being the main watershed of the island for some distance, the conditions are better: the ridge is not so intensely dissected by the *barranco*-erosion. Dikes are abundant in the upper regions. Many very

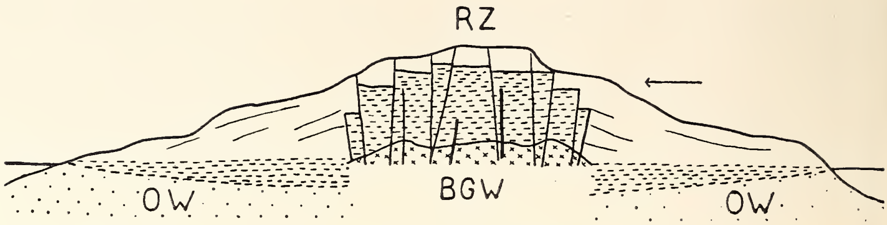

Fig. 9. Schem. cross-section through Cumbre de Pedro Gil, main watershed of Tenerife, with its ground water conditions: *RZ* = the rift-zone with the high level ground water. *BGW* = basal ground water, floating on *OW* = ocean water impregnation. Arrow to the right = direction of the trade-wind (from N).

productive tunnels have been opened here both in the N and in the S slopes, the latter including the heads of the fertile Guimar valley (fig. 9).

Montaña Izaña can be regarded as the WSW end on the Cumbre de Pedro Gil. From here a highland of some flatness extends westwards to the rim of Las Cañadas. The ground is hidden beneath younger volcanic products. No doubt here is a good catching ground for the rain and the melt water of the winter snow, as we shall find later on.

The crescent-like mountain ridge of Las Cañadas, lying to the SE and S of Pico de Teide, consists, as said above mostly of distally dipping sheets of phonolitic lavas with intercalated pyroklastics. The whole complex is cut by numerous dikes of various orientations. The mountains are an important high-level-ground-water-reservoir, being exploited long times ago. But there seems to be some irregularities in the distribution of the ground water quantities, since tunnelling works have proved less profitable in some sectors.

It is a common opinion among Canarians occupied in the search and the exploitation of ground water, that the great basin of Caldera de las Cañadas may be considered as a giant catching ground for rain water and the melt-water of the winter snow, and that this water accumulated will supply the ground water streams moving outward into the slopes.

Many collapse-calderas in the world have as is known a lake occupying it and forming a deep reservoir of clear water. This is the case with the well known Crater Lake in Oregon, U.S.A., the deepest lake in the Union. But Caldera de las Cañadas is completely dry. This fact is to some degree due to scarce rainfall (ab. 350 mm yearly, according to earlier measurements during only four years) partly naturally to the very permeable bottom of the Caldera and likewise to the porous lava fields radiating from Pico de Teide in extensive fan-shaped tongues.

The area of the Caldera measures ab. 200 sq. km. The surface in question

receives thence an annual quantity of water of ab. 70 mill. cub. m. Of this amount probably the half part is evaporated due to the intense insolation governing these regions above the clouds.

It is, however, very questionable if all the remaining quantity (35 mill. cub. m.) will be disposable for the ground water circulation in the surrounding mountains. We must suppose that a great deal of the water percolating into the interior of the Caldera meets with the volcanic heat and changes into steam. This again rises to the surface.

Pico de Teide is now in the solfataric stage and the gases issuing from the top crater and from La Rambleta (the old crater occupied by the youngest cone El Piton) have a temperature of ab. 80° C (A. Brun). And the top of the volcano rises ab. 1700 m above the bottom of La Caldera.

It is thence probable that an underground with more than 100° C is met with already at the base of the volcano and that the iso-geotermal surfaces under the bottom of the Caldera rise to great heights in the shape of a »dome». Moreover the isogeotermal surfaces lie near one to another, the termal gradient being here steep.

The percolating ground water changed into steam will under these conditions be prevented from taking part in the supply to the peripherical mountains. The rising steam issues to some degree in the volcano itself (mingled with the solfataric gases), partly it is condensed in the surrounding superficial ground. But this water is further forced upward to the surface because of evaporation.

The region of the interior volcanic heat is as it seems not confined to the underground of the central volcano and the nearer surroundings. Westward from Pico Viejo there extends a highland crowned with many cinder cones, the youngest of these being the above mentioned Chinyero from the year 1909. This broad ridge, being the main watershed in this part of the island is known as Talus de Bilma. The ridge is a good catching ground for the rain water, but if there is any storage of it in the underground is quite dubious. The whole area is covered with young volcanic material, so that the composition of the deeper parts is unknown. — No tunnelling operations have been started in the neighbourhood, except what is to be found in the upper part of the Santiago tectonical valley bordering on the highland in the W.

There is a great abundance of cinder cones in Talus de Bilma. May there be any connexion between the frequency of local outbursts and the inflow of water?

Leaving now the high mountains and descending to the coasts in the S parts of the island and also to the strip of lowland along the W coast, we find

here the shafts and wells for exploiting the basal ground water. Many such shafts have been dug, but not all have supplied water. The water obtained is seldom potable but can be used for the tomato fields. The shafts are never met with at altitudes above the 200 m contour line.

The production of water for the irrigation of the vast regions in the dry South of the island is a problem of constantly growing importance. The soil here is generally fertile and the climate good, this side being sheltered from the cooler north winds. — The only thing that fails here is good water, especially for the use in banana-plantations.

Recently has been considered the possibility of transferring by way of pipe lines the surplus of water encoutered on the windward sides of the island. But in reality the »surplus» in question has proved quite imaginary, and the pipe line would be too expensive for such an undertaking, in the case that water was at the disposal.

Fortunately some years ago rich storages of high level ground water were met with by tunnelling in the mountain sector between Fasnia and Arico on the SE slopes of the island. To distribute the water from here a company was formed: »*Aguas del Sur*» (»The Southern Waters») and a *canal* (pipe line) has already been constructed with a length of 70 km (1950) to transfer the water to the *ayuntamientos* of Granadilla, Arona, Adeje etc., where the drought is severe.

The abundance of ground water in the mentioned sector is due to a good catching ground in the alpine region between Mta Izaña and the Cañadas.

G r a n C a n a r i a. — In the easterly direction from Tenerife lies the island of Gran Canaria with an areal extension of ab. 1380 sq. km. The island has a quite rounded contour, it is a shield with the culminating point near to the center (nearly 2000 m). The hydrographic system is radiating.

The geology of Gran Canaria is as that of Tenerife quite complicated. There are many different volcanic formations, of very different ages too. A preliminary geological map of the island has been quite recently elaborated by J. Bourcart. Later complementary observations have been made by a Canarian geologist S. Benítez Padilla.

Parts of an old basaltic substratum are seen on the W coast and on the E slopes. In all other regions the basal ground is covered with younger lava flows of phonolitic, trachytic, and rhyolitic composition. These all are covered with an »andesitic breccia», perhaps deposits from a »Peléean» eruption in the center of the island. — Later on basaltic effusions have occurred in the NE half of the island, and there are many cinder cones. No historical outbursts are known from the island.

The inclination of the different volcanic sheets is not so regular as one may suppose from the shield-like shape of the island. The dip of the old basaltic formation on the W and NW coast is towards the interior. But in other sectors the dip is as far as I have seen mostly distally directed.

The wind regimen is in Gran Canaria similar to that in Tenerife but the windward side is here not so extensive. On the other hand the central heights are not, as in Tenerife, replaced by a *caldera*, whose bottom is above the clouds and where rainfall is scarce.

Studying the pluviometric map of Gran Canaria one observes (fig. 7) that the lines form a quite concentric system with the central maximum in the region of Valleseco (790 mm).[1] From this spot the amount of the rainfall diminishes continuously in all directions, so that the coastal strip along the NE and N coast has only 100—200 mm. A broad belt of desert climate extends along the whole W, S and SE coast, the maximal width being in the S. — There are consequently great regional differences in an island measuring only ab. 45 km in diameter! The concentration of rainfall in the inland is due to the orography: the moisture of the trade-winds is condensed against the orographic center, and the above mentioned village Valleseco lies in the clouds.

Generally speaking there seems to be a better catching ground for the atmospheric water in this island than in Tenerife, and it would be still better if there did not exist some very deep and wide *caldera*-like valleys dissecting the central mountain mass: Caldera de Tejéda, Caldera de Tirajána and Valle de Tenteniguáda. But on the other hand these valleys have many springs in the slopes, and water can here be obtained for the local needs.

Nevertheless there is still much catching ground in the mountains swept by the trade-wind clouds in heights above 1000 m. High level ground water accumulates here under the same circumstances as in Tenerife: perching ash beds and confining dikes of steep inclination. Of the trend of these dikes the author has no nearer knowledge and no such data can be obtained from the literature. The island has not a long mountain axis; instead of a such there are many secondary ridges radiating from an orographic center (region of Pozo de Nieve). But if there are in the same manner radiating dikes the author does not know.

The basal ground water table which in Tenerife is exploitable mostly in the southern and W coastal strips, is in Gran Canaria more extensively at

[1] The name of the place is highly misleading in this connection (*Valleseco* = The dry valley).

hand. In the low coastal flats all around the island except the W sector (disregarding the valley bottoms here) the ground water level lies at insignificant depths. Also in the zone 250—500 m this water table is attainable by wells and shafts. — As we shall see these coastal regions correspond to the zone of wells and shafts in a number not known in Tenerife.

F u e r t e v e n t u r a. — This island, one of the so called »Purpuraries», has a nature quite different from that of the western islands, both regarding the orography, geology, and also the climatic conditions. The area comprises ab. 1720 sq. km; a superficie considerably vaster than that of Gran Canaria. The heights are, however, more insignificant. The culminating point (in the S peninsula Jandía) attains 855 m and the so called Atalaya Mountains on the NW coast are somewhat lower. The coasts are generally not high, except in Jandia and in the strip opposite the Atalaya Mts.

The orography is that of a typical erosion landscape, and volcanic cones are rare. Except Jandia and Atalaya Mts where deep erosion gorges (*barrancos*) are to be found, the island has many broad open valleys with a flat bottom. Some of the valleys are old water gaps. There are also smooth basin grounds and coastal plains.

The geology of Fuerteventura was investigated already hundred years ago by G. Hartung. In more recent years J. Bourcart has paid a short visit to the island. Much work is still to be done before the stratigraphic relations and the petrology are cleared up. The demand is now more justified regarding the fact that a modern topographic map of the island is available, the first one of all the Canaries.

According to the author's impressions from a stay in 1950 the island has a b a s e m e n t of old plutonic rocks[1] intermingled with metabasites, etc. The general trend of the old rocks seems to be ab. NE—SW. This complex is capped by a peneplane, on which an extensive basaltic formation has been deposited. The basement has in later times been somewhat dislocated so that a horst block — the Atalaya Mts — has been formed. But on the whole the basalt formation lies quite horizontal. This typical plateau basalt has afterwards been dissected by the erosion and broad valleys have been formed, reducing the basalt plateau to more or less isolated table mountains and buttes.

After the formation of the valley systems there occurred outpourings of

[1] The old basement has a wider extension than what is exposed in the Atalaya Mountains. During an excursion from Puerto Cabras to the inland the author found in the foot of a basaltic table mountain 6 km from the port plutonic rocks belonging to the same assemblage as that exposed in the Atalaya.

basaltic lavas, and these streams filled the bottoms of the valleys to a considerable thickness. Hence the flatness of many of the valley bottoms.

Lastly in the Quaternary (?) and historical times a new volcanic activity appeared, the latest being contemporaneous with the great outbursts in the near lying Lanzarote (1730—36).

The wind regimen of Fuerteventura has already been alluded to. The island is dominated nearly the whole year by a strong N or NW gale, and the relative flatness of the ground with the absence of bordering mountains in the N makes it clear that a condensation of the humidity of the air masses is out of the question. In fact Fuerteventura is the driest of all the Canary Islands. The author has no mean figures of the amount of rainfall at hand, but it is a known fact that there is no rain during the whole year except in some days in the winter. On such occasions the population recovers the quantity of rain water in cement tanks of a special construction to prevent later evaporation. This quantity (perhaps with some occasional addition) must be sufficient enough for the whole year!

About the ground water possibilities of Fuerteventura there are but scarce data at ones disposal. No systematic investigations have up to date been made here. The small settlements and villages of the very scarce population catch their water for irrigation from wells by wind motor pumps. But these wells do not reach more than some ten m below the surface of the valleys, and the water brought up is brackish.

Banana-cultures are here consequently out of the question although the soil is fertile, and tropical to sub-tropical temperatures dominate the greater part of the year.

Regarding the ground water streams and a probable existence of natural stores the author got the impression that the whole island is underlain by a fresh water body — the basal ground water. This body may be accessible when boring from the bottom of the valleys to depths not beyond economic possibilities. The wells existing have reached only secondary ground water levels perched by tuff layers intercalated between the lava sheets. No doubt these lava fills are resting on some bottom gravels and sands, *and in these the main water body may be reached.* In short: the borings made up to this time have reached too shallow depths (Cfr. fig. 10).

It seems probable that the Atalaya Mts form the subterranean hydrographic center of the middle part of the island.

In the bottom of the lower part of the Valley of Gran Tarajál, in the southern region of Fuerteventura there exists a ground water body apparently quite near to the surface, which consists of alluvial material. The water brought

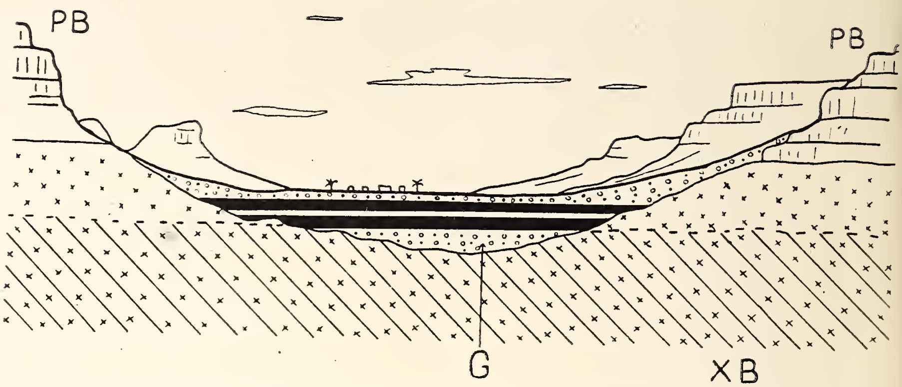

Fig. 10. Schem. cross section of a mature valley in Fuerteventura showing ground water conditions (according to the author's conception). XB = Crystalline basement. PB = The plateau basalt-formation. Black = Younger basaltic valley fill. G = Bottom-river gravel (buried), the main aquifer. Obliquely stripped = Ground water saturation.

up with wind motor pumps is brackish. The fields lie only some ms above the sea level.

A very interesting phenomenon in Fuerteventura are the mighty deposits of travertine, covering almost all the level grounds in the interior and also along the coasts. The origin of this lime formation has been much discussed since the days of von Buch. It is apparent that the precipitation of the lime is due to the strong evaporation. The source of the lime lies in the mineral constituents of the widespread basaltic rocks: the plagioclase and the pyroxene. The subterranean water has dissolved the minerals in some parts and the solutions have been forced upwards to the surface by the evaporation. — None of the Canaries has such a copious lime precipitation as Fuerteventura.

Lanzarote. — Turning now to the island of the Canaries situated in the extreme NE we find here conditions of a quite similar nature as in Fuerteventura. Lanzarote has an area of ab. 730 sq. km and is consequently much smaller than its neighbour in SW. The heights are moderate and they do not work as moisture condenser of the air masses swept over the island from the northerly directions nearly the whole year. It is a desolate landscape of extreme dryness very similar to Fuerteventura. The great number of volcanic cones dotted over nearly the whole island gives, however, a different aspect. Lanzarote has been called »*Isla de los Volcanes*», not a very original name indeed being one of the members in the Canarian volcanic family! Nevertheless the cones here are very dominating in the landscape from one end of the

Fig. 11. A part of the high NE coastal cliff Acantilado de Famára in Lanzarote with Golfo de Penedo to the right. An old land block is here cut across by a fault zone, the sunken area lying to the right, in the background. At the foot of this precipice a tunnel has been opened to provide the capital of Lanzarote. Arrecife, with water. Photo by the author 1950.

island to the other. The heights of the cones are, however, quite moderate: none attains much more than 500 m.

The geological structure of Lanzarote has been studied years ago by E. H. PACHECO and also a geological map of his hand exists. The most remarkable feature of the island is a threefold division into the following units: in the N there is a block of an old basaltic formation, tilted to the E, and area forming an escarpment along the NW-coast, the so called Acantilado de Famára (fig. 11). In the middle of the island we have a area downfaulted with a heavy overburden of young volcanic material comprising two rows of volcanic cones, among which there are the volcanoes of historical times (1730—36 and 1824). In the S part we meet with another old block of basaltic lavas etc., likewise tilted to the E and called Los Ajáches. To the W is a bluff, but not bordered by the sea —, there extends a plain lowland — a sunken part.

Young cinder cones are by no means absent in the N and in the S.

The barren landscape of Lanzarote is swept by the strong trade-winds from N and NW, and no obstacles are met with which could provoke a condensation of the humidity of the air masses. Only Acantilado de Famára may sometimes bear a cloud cap. — The rain comes in winter but scarcely and occasionally. The population must trust to these rain quantities for their domestic use, when potable water is demanded.

High level ground water seems to be present to some degree in Acantilado de Famára, judging from the recently started construction of a tunnel in the bluff near to Bahia de Penedo. That there exists a ground water stream mowing E in the region of Haria is mentioned in the paper of BOURCART. According to him there is water obtainable from a depth of 45 m (shaft?) producing ab. 75 cub. m. daily.

The formation of travertine is in Lanzarote nearly as extensive as in Fuerteventura, but the quantity is much inferior.

The irrigation cultures.

As we have found in the foregoing, the annual amount of rain in the Canaries is far from sufficient to give the necessary water for the cultures in the lowlands, where the temperature is high enough to allow the raising of tropical and sub-tropical plants. The water required must be taken either from wells and shafts or from tunnels at the higher levels — from the region of the clouds. In the last fifty years there has been done much labour to exploit the ground water of different levels. Before turning our attention to the cultures we may shortly look at the technical means to recover the water, here and there touched upon already in the foregoing chapters.

Recovery of the water.

The water to be used for irrigation purposes is in the Canaries as we have found of three different kinds: 1) superficial rain water, never potable, running often with great force due to the steep gradient of the *barrancos*. These »rivers» are, however, of short duration; 2) high level ground water, mostly of good quality, perched by impermeable layers in the ground and confined by dikes; 3) basal ground water, lying in deep levels, the limit of saturation against the vadose zone being slightly above the ocean level. This water is mostly fresh but along the coasts where it is exploited, intermingling with salt water often takes place.

To catch the superficial water there are many difficulties. Dams to store it have been erected especially in Gran Canaria, but the conditions are often unfavourable, and the expenses high. In Tenerife the construction of dams has been practized in but a few places. The *barrancos* are too steep, and the water runs with great violence carrying with it stones and boulders. When such a burden on its way down the bottom meets a dam, the stones work as

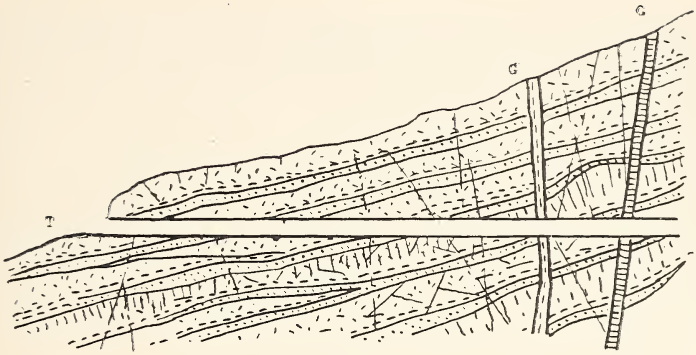

Fig. 12. Schem. cross-section through a part of the S slopes of the Cañadas Mountains, Tenerife, showing the location of a tunnel (with a slight gradient to the left) dissecting successively the tilted tuff layers and (at the right) also two dikes (G). Water issues at every crossing with the tuff layers and also from behind the left-hand dike.

Fig. 13. A part of the N wall of Barranco de Chirche, above Guia de Isora, W slope of Tenerife, showing a succession of phonolitic lava beds separated by impermeable tuff layers. At the base: part of the pipe line conducting water from Galeria Chirche, whose entrance lies some hundred m:s to the right from this place. Photo by the author 1950.

artillery shots damaging or destroying the construction. Moreover the walls of the *barrancos* are at the dam often permeable to such a degree that a lining with cement is necessary.

Dams in Tenerife are to be found above Santa Cruz and in Arona. Surplus of the winter rain water is collected in the Orotava valley into a huge tank, lying in the vicinity of the town Orotava. It receives the water from the near lying Barranco de las Arenas, the sources of which are situated at the foot of the precipices of Aguamansa. The tank was constructed in the eighties by señores ASCANIO, according to a notice found in a paper by NAVARRO (1924).

The dams erected in Gran Canaria are numerous and often of considerable dimensions. Most of these are situated in the northern sector of the island, where the *barrancos* in time of rain are filled with the running water. They lie not far from the coast (between Santa Brigida in the N and Galdar in the NW). But also on the dry southern slopes of the island some dams have been erected, all belonging to the Insular Government (*Cabildo Insulár de Gran Canaria*).

Two of the dams in the south are destined to furnish water for a canal projected to embrace nearly the whole central highland. This canal will consist of a southern and a northern sector, both bringing water to the region of Las Palmas, where the most intense cultures are to be found, but giving off water also to many other sectors. We cannot enter here into more details regarding the plan of this great and expensive public work, which in a nearer future will rationalize the irrigation of Gran Canaria on a new basis.

The most important means of recovery of ground water in the Canaries is the digging of tunnels. There are two kinds of tunnels: mountain tunnels and shaft tunnels near the coasts. Now we shall regard somewhat more closely the construction of the former class of tunnels.

The mountain tunnels are opened nearly exclusively in the bottom of the *barrancos*, at very different levels. Most of the tunnels lie in the forest zone, *el pinár*, on heights of ab. 1000—1500 m. But there are also some lower-situated. The idea with the mountain tunnels is to catch the water moving along impermeable tuff layers, tilted towards the coast. At every point where the tunnel crosses a tuff layer (under a very acute angle) there is a drop or a feeble inflow of water. When the tunnel reaches a length of 1000 to 2000 m, there may be several of these »water points».

Still better conditions are to be found when the tunnel crosses a steeply inclined dike of relative impermeability. The ground water may in this case be stored behind the dike in a compartment with a water table lying consider-

Fig. 14. The entrance to the tunnel »Galería Cruz de la Niña» in the vicinity of Vilaflor, Tenerife, ab. 1600 m above the sea. When the picture was taken the front of the tunnel was at 800 m from the entrance, but water was not yet visible. Photo by the author 1948.

ably higher. It depends on the dimensions of the chamber and on the rate of percolation of water from above how abundant the spring in the tunnel may be, how long time this inflow lasts, if the production may be satisfactory. In many cases the initial abundancy of water diminishes rapidly, later on being more constant but modest, until the progressing digging work meets with another dike to be crossed. Then the spectacle can be repeated.[1]

Many of the tunnels do not reach the high level storage compartments but are opened at lower levels, outside the zone of dikes. In such cases the tunnel crosses a series of inclined lava sheets with intercalated more or less impermeable tuff-layers. There are avenues of ground water motion on the upper surface of such layers, and from these the water drops into the tunnel. In such cases the productivity is not very abundant but instead more conti-

[1] Some of the high level tunnelling works in the Cañadas Mountains, Tenerife, have at last experienced such an elevated temperature — due to the nearness of the central volcanic heat — that digging has been suspended.

nuous. But there are also cases when the tunnelling ends in failure. Such tunnels are often digged along the axis of a ridge separating two *barrancos* from one another. In such a situation the *barrancos* have drained a great deal of the separate ground water streams, and the extracted water appears as many small springs in the sides of the *barranco.* In short such a tunnel has been located in a too intensely eroded landscape.

The direction of a tunnel can in the course of the work be changed one or several times, and also branches are digged out with the hope of meeting some rich ground water streams. The final length of the tunnel reaches in some cases up to 2 and even 3 km, but many times the yield has not been in proportion to the heavy expenses. The cross-profile of a tunnel is 2×1.5 m. The blasted rock material is hauled out to the *barranco* with mining cars along a track. Alongside with one wall of the tunnel is the canal carrying the water out to the distribution net. To get this outflow of water one must be aware that the bottom of the tunnel has a slight gradient.

In the last years the tunnelling work has been very intensified both in Tenerife and in Gran Canaria. The total length of the tunnels in the mountains was in the latter island in 1949 — ab. 75 km.

The huge costs of these operations are financed either by large enterprises, by the Insular Government or by local companies called *comunidades de agua.*

Water produced from the mountain tunnels was in Tenerife in the year 1948 — ab. 94.553.000 cub. m. Now the quantity is considerably higher but the author has not the figures at hand. The same can be said also about Gran Canaria. — Most of the water from tunnels goes to the banana plantations, a part to the cities and villages for domestic consumption.

Another mean, alluded to in the foregoing chapters is the recovery by way of water shafts (*pozos*) and wells. These operations are practized in the low coastal regions, chiefly in Gran Canaria and in Tenerife. The far greater number of *pozos* is to be found in the eastern lowland of Gran Canaria up to levels of ab. 300 m and more. In Tenerife the conditions are less favourable due to the steepness of the coast except on the southern side and in a strip along the western coast. Also in the lower part of the Guimar valley there are some *pozos.*

The depth of the *pozos* is very varying depending on the nearness to the shore. Depths of 100 m are not rare and there are some of 150 m and more. To recover the greatest possible quantity of the basal ground water horizontal tunnels are digged sideways from the shaft, often in different levels. Many times these *pozos* have proved less productive and do not correspond to the expenses; some of the diggings have ended in a complete failure. As

Fig. 15. Part of a pipe line at Barranco Hondo, Tenerife, conducting tunnel-water from the Guimar valley to Santa Cruz, SE slopes of the island. To the right a tank (*charco*) for the local demand. Photo by the author 1948.

already mentioned the water pumped up is mostly brackish. Although the content of salt may be quite insignificant, a prolonged use of it in the irrigation of the ground increases the salinity of the latter to such a degree that the area in question must be abandoned for a long time or until occasional rains have washed away the salt content. It is the intense evaporation which concentrates the salinity in the soil.

Different kinds of plantations.

The most important kinds of plantations using the irrigation water are the banana- and the tomato-cultures, the *platanales* and the *tomatéras*. Next tn order are the *potato fields*, *maiz* etc. These irrigation cultures confined to she warm coastal lands, are partly on the windward partly on the leeward tide of the islands. They lie all below the 400 m contour line, many times in ihe immediate vicinity of the coast. The climate dominating in these regions is as we have seen warm and dry, and the winters are mild although occasionally somewhat windy.

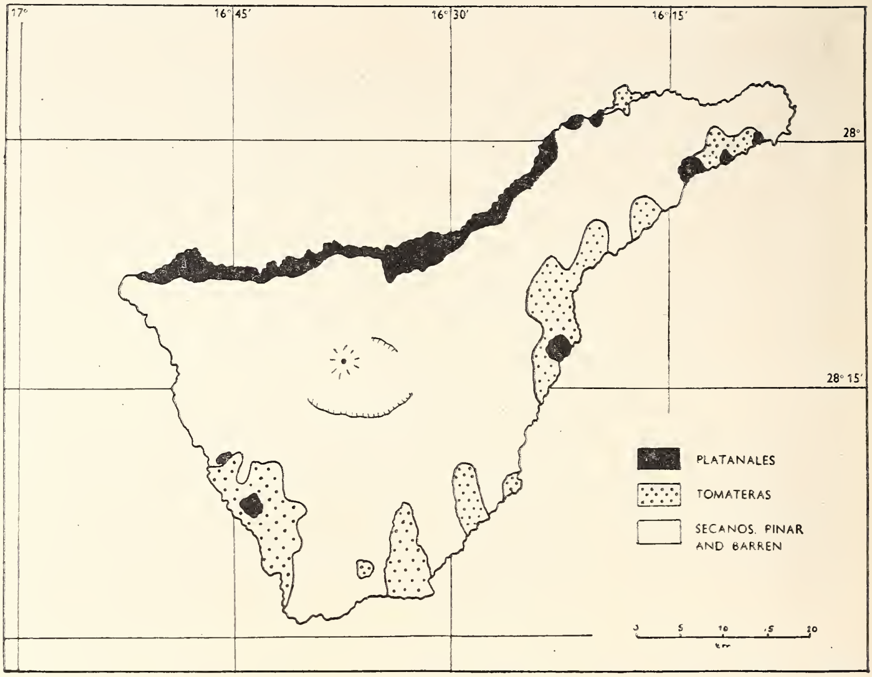

Fig. 16. Sketch map of Tenerife showing the main irrigation cultures. From Banco de Vizcaya, Rev. financiera 1950.

Platanales.[1] — The banana-cultures (*musa chinensis*) require very expensive constructional works, not only regarding the distribution of the water caught from the high level tunnels by way of canals and a distribution net including tanks of cement, but also in the sense that a special ground must be created. The Canary Islands are as we have seen mostly volcanic masses without any such soil cover, that is to be found in the European countries. Moreover the declivities are generally steep, often 20° and more, so that the rain water has a great eroding power. It is therefore necessary to construct terraces with solid walls of heavy stones carefully joined together. The room inside the walls is filled with soil, mostly brought together from more or less distant localities where occasional soil is to be found sufficiently. These terraces follow one above the other up the slopes in a long succession or up to levels of ab. 300 or max. 400 m.

[1] Derived from the Spanish word *plátano* = banana.

The soil brought together in such a way is of different quality but generally it is quite fertile as in most volcanic lands. The bananaplant requires, however, as known abundant nutritive substances in addition, and the rates of fertilizers used here are as follows (Ahlers 1925):

Ammonium sulphate	40 %
Calcium superphosphate	27 %
Potassium sulphate	28 %
(Gypsum	5 %)

The amount for a single plant is annually 2.5 kg.

To these substances must be added also stall dung in winter. The irrigation is performed with intervals from 10 to 20 days.

The banana cultures or *platanáles* represent the areas under a continuous

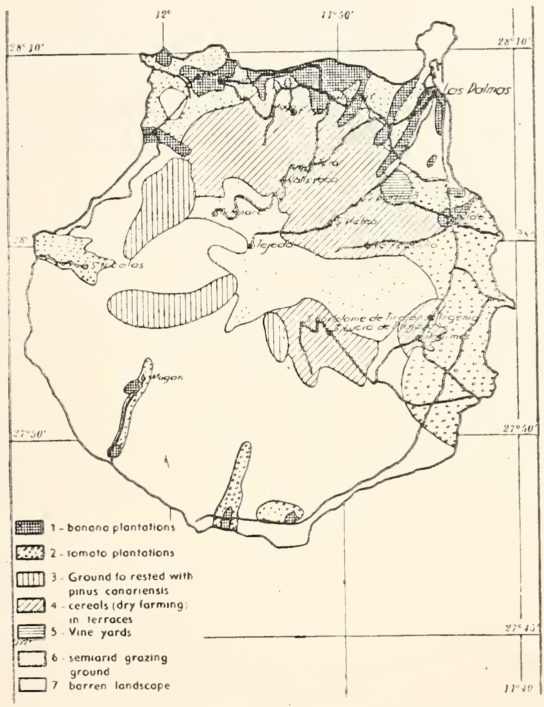

Fig. 17. Map of Gran Canaria showing the location of different cultures including also forests and grazing ground. 1 — banana plantations; 2 — tomato plantations; 3 — ground forested with pinus canariensis; 4 — cereals (dry farming) in terraces; 5 — vine-yards; 6 — semiarid grazing ground; 7 — barren landscape. Obras hidráulicas de Gran Canaria. Memoria del Ex:mo Cabildo Insular. Las Palmas 1947.

irrigation. In the 4 western islands these cultures occupy an area of 4.800 ha, and the quality of the water must be high, or without any salinity.

In Gran Canaria the area of the *platanáles* comprises ab. 8.000 ha. Consequently this island has the most extensive cultures of this class.

The cultivation of bananas began at the end of the last century. Since that time the production has made a very rapid progress. Now all the suitable places on the lower windward sides of the islands (except in Hierro!) are occupied by the banana-terraces. But also the dry leeward sides have some scattered places where the banana plantations have been possible. The only question is how to procure water, the soil being mostly fertile and the places in question are generally sheltered from storm winds. The two maps of Tenerife and Gran Canaria respectively may indicate the nearer extension of the platanáles (Fig. 16 and 17).

T o m a t é r a s. — Shortly after the introduction of the banana cultures the tomato began to be an important produce of the Canaries. The tomato plantations lie as the banana fields in the vicinity of the coasts. Their water demand in somewhat less. The *tomateras* do not occupy the soil more than a couple of months, when they are irrigated. In the case of the location of *tomateras* they prefer a sunny and sheltered place near to the coasts. The leeward sides are very suitable for these plantations. Moreover they prefer a somewhat brackish water, consequently the water from the *pozos* is to be used.

The areas occupied by *tomatéras* are extensive (Fig. 16, 17) and the expansion is still going on. In the western islands the *tomatéras* comprise (1950) an area of ab. 4000 ha, in Gran Canaria ab. 7.500 ha the chief region being here the lowlands on the eastern coast. In Fuerteventura and Lanzarote the culture in question has likewise made a rapid progress. Thus the lower part of the valley of Gran Tarajál, formerly a desolate gravel plain is now occupied by *tomatéras* and alfalfa-cultures, and the water is recovered by wind motor pumps from wells. The alfalfa grass prefers likewise the brackish water obtainable here.

The two kinds of fruits are the most important produces of export to Europe. The greater part of the bananas is going to the motherland, Spain; in the years 1948 and 1949 England was next in order. The total amount in 1949 was 147.699.320 kg, this amount being lower than that of the foregoing year, which fact is due to the continuous drought in 1949.

The tomato export going on during the winter season, attained in 1948—49 the amount of 14.296.348 kg, the bulk of which was exported to England. Gran Canaria is the chief producer of this fruit (ab. 60—65 %).

A quite important produce in Canarias is the p o t a t o, being exported to a great deal, chiefly to England. The amount exported in the last years

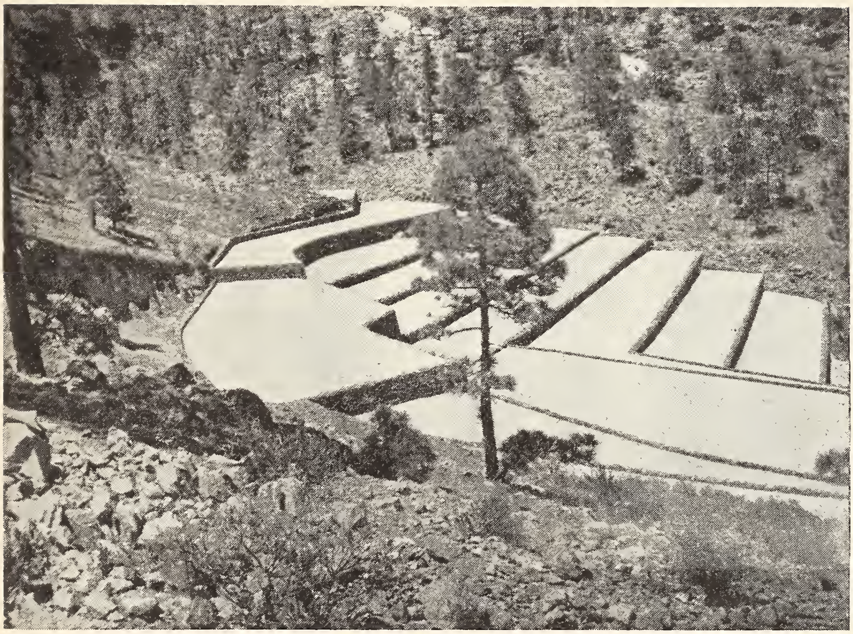

Fig. 18. A »stairway» of potato-fields on a mountain slope near to Vilaflor Tene rife, ab. 1500 m above the sea. The surface of the terraces is covered with pumice lapilli to prevent the evaporation of water from the occasional rains. This kind of cultures is called *»secanos»* (dry farming). Photo by the author 1948.

approaches to 10 mill. kg. The potato-fields are situated partly in the coastal region, where they are irrigated, partly on the slopes under the clouds, where they receive some rain, but where it is necessary to cover the superficies with a sheet of lapilli (*»jáble»*) to prevent the evaporation (see the pict. fig. 18).

Other cultures practized in the Canarias are t o b a c c o and m a i z, and to a smaller extent c o t t o n. All these plants demand irrigation, but they occupy the ground only for some months in the year. The tobacco cultures have made rapid progress in the eastern islands in the last years.

Concluding remarks.

This paper deals as we have seen principally with the ground water possibilities in the Canaries and with the recovery of the water. The theme in question is of great interest: we have here to do with ground water conditions wholly different from those governing most of the European and American countries,

where the best aquifers consist of some wide reaching sedimentary strata in flat lying position, or where we have some wide basins with a series of alternating permeable and impermeable sediments. In the both cases artesian water can often be obtained.

In the Canaries the conditions are wholly different. The volcanic ground is of its special nature with rapidly changing lithologic complexes, being of different composition and permeability and having very capricious mutual relations. The ways of motion of the ground water are likewise capricious and are very difficult to investigate. The means of recovery are of special kinds and this planning includes a hazardous job. But when the water really is obtainable in abundance, it is of the highest value: the climate and the soil are good, the only thing that was demanded is water to secure the crop of the various kinds of Canarian produces, bringing a great profit in the European market.

The most important question to be answered regarding the water is if there is enough of it in the Canaries to secure the rapidly growing demand. It is still uncertain if the present consumption of ground water approaches to the amount of the atmospheric water supply percolating into the ground of the mountains, or if there may possibly be a larger »margin» for the future? The total amount of water recovered from both tunnels, springs and *pozos* was in:

Tenerife	in the year 1948	108.675.000	cub.	meters
Gran Canaria	» » » 1949	132.829.600	»	»

Concerning Tenerife the larger part belongs to the tunnel production.

To clear up the question and to establish a balance it is necessary to obtain meteorological data of a longer series, e s p e c i a l l y f r o m t h e h i g h e r m o u n t a i n s, w h e r e t h e p r i n c i p a l i n f l o w o f w a t e r t a k e s p l a c e.

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[1] No references will here be made to the extensive literature on Canarian geology which is to be treated in a special memoir.

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Text 93 pages, 36 figures, 4 maps, and 2 diagrams in the text.